

NOvA Offaxis Totally Active Detector

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NOvA Collaboration Meeting

Fermilab

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Outline

- Parameters of the Detector
- Description of Analysis
- Detector Performance
- First Results from Simulations
- Possible Improvements in Analysis
- Future



Detector Parameters

- 2000 planes, alternating in x and y
- Each plane is 17.5 x 17.5 m
- Each plane has 14 extrusion
- Each extrusion has 32 cells, filled with liquid scintillator
- Cell dimensions are 3.8 x 4.5 cm
- Extrusion walls are 1 mm on the inside, 2mm on the outside



Detector (ctd)

- These parameters result in a detector of about 26 kt
- The non-active mass is about 13%
- A crude cost estimate give a total cost for such a detector that is roughly the same as baseline detector of 50 kt
- The simulations are based on a total mass of 25 kt



Outline of Analysis

- Initial reconstruction
 - Up to 4 tracks are found (>6 hits)
 - A quadratic fit is made, ph weighted in each plane
 - Each projection is treated independently
- A vertex is calculated (or defined)
- Assignment of particle identity is made based on a set of track parameters calculated
 - Particles are labeled as e, μ , p, or γ
 - Only 1 e, μ , or p are allowed
 - If 2 or more satisfy e criteria, the “best” one is chosen
- Ntuple file is written out with track parameters and converted to root format



Analysis (2nd stage)

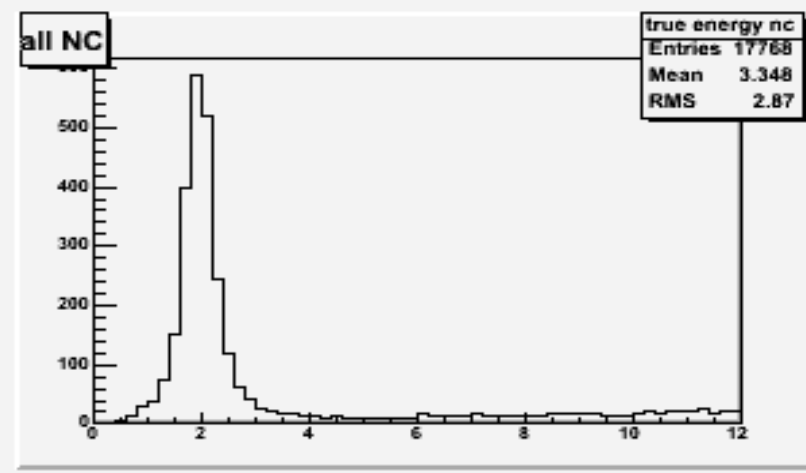
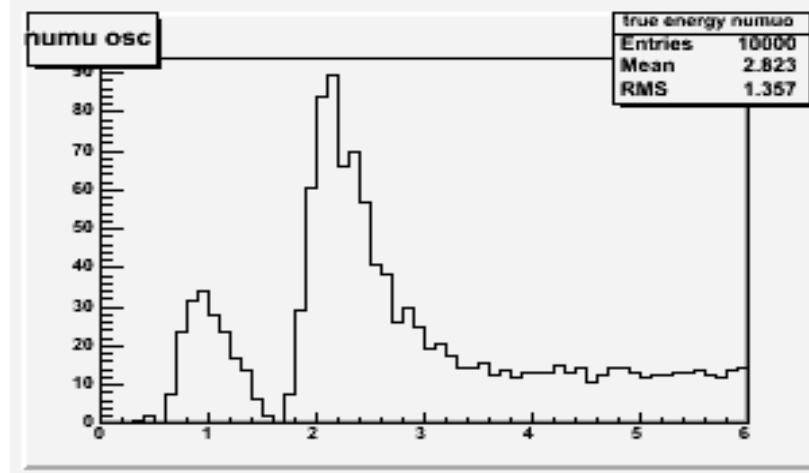
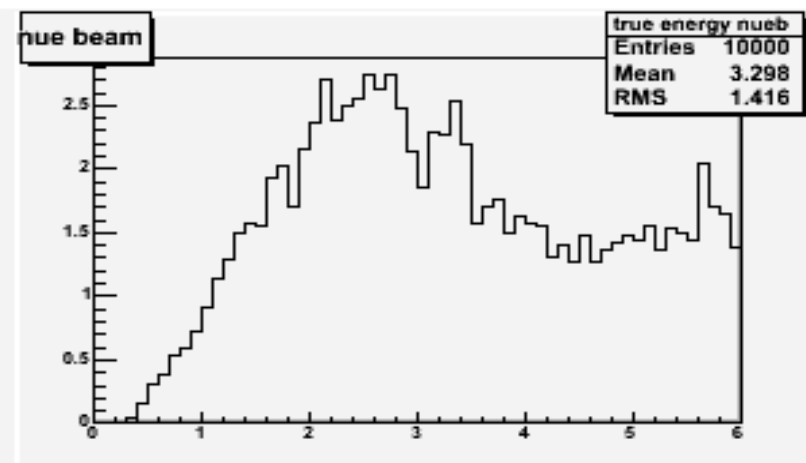
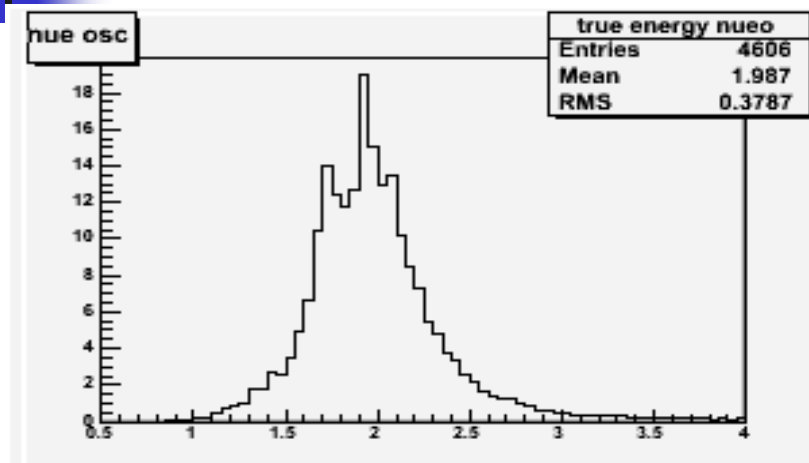
- Initial sample of e candidate events is selected, requiring:
 - Electron track in each view
 - Energy in right range
 - No μ or γ in event
 - No significant separation of “electron” from the vertex
 - No gaps near vertex
- Subsequent analysis is based on maximum likelihood method using about 9-14 different variables describing track and event “nature”
- So far only 1D distributions have been used in maximum likelihood calculation.
- In parallel there is also cuts-only analysis



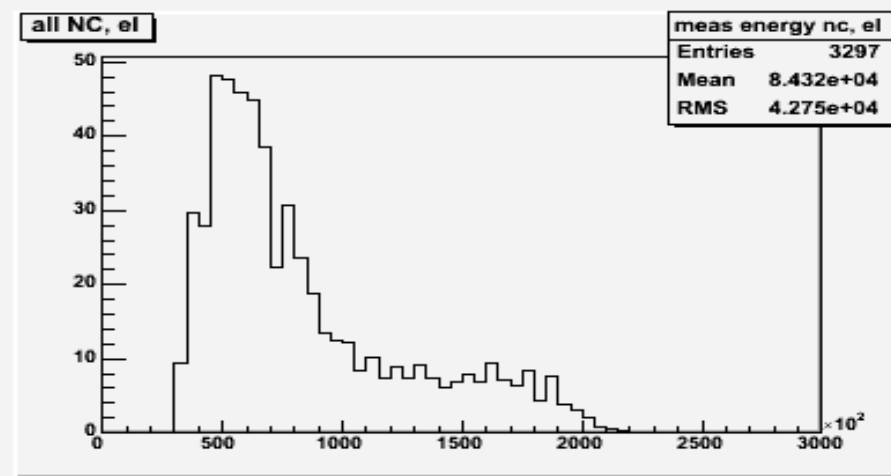
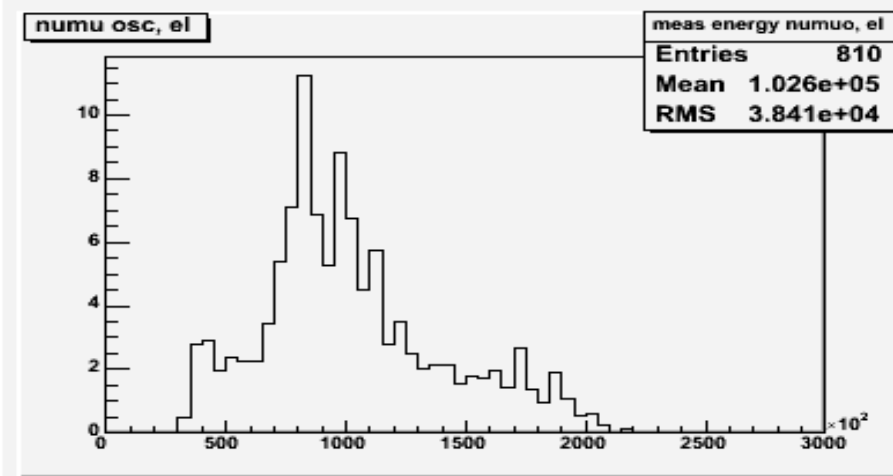
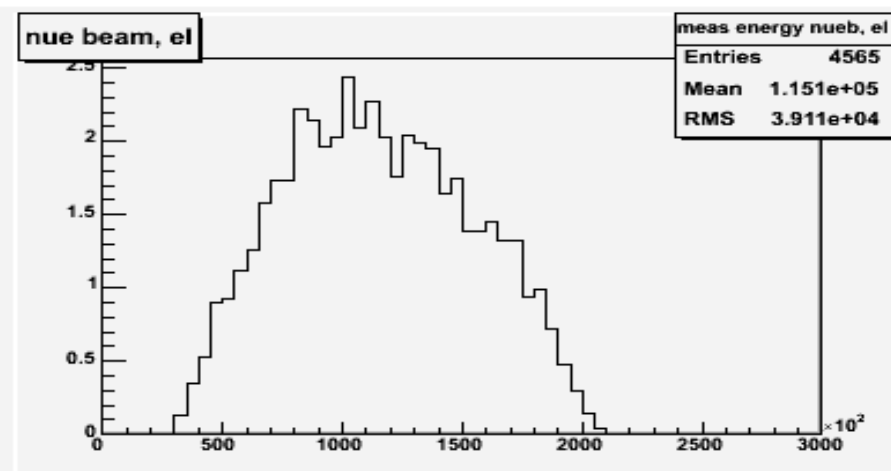
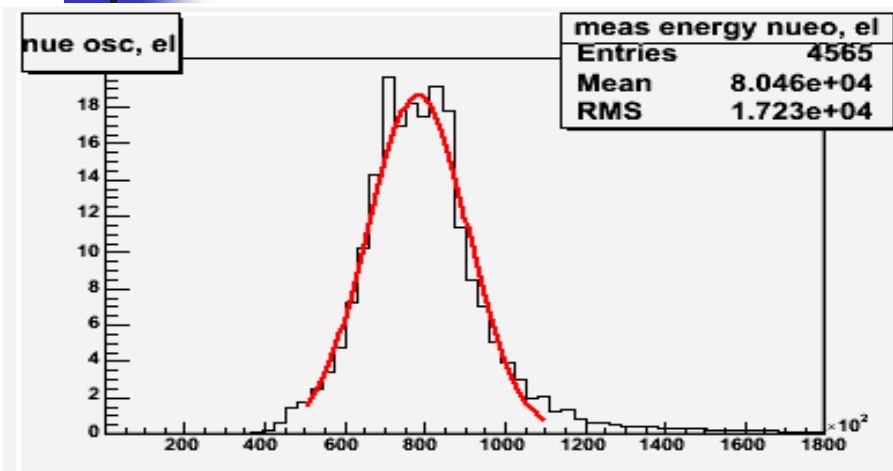
Detector Performance

- To give an idea of the performance of this detector we show next several relevant distributions:
 - Energy resolution for electron events
 - Electron/muon comparison for several variables used in ML calculation
 - Comparison of several distributions used in ML for both signal and background events (NC and CC only, except for energy)

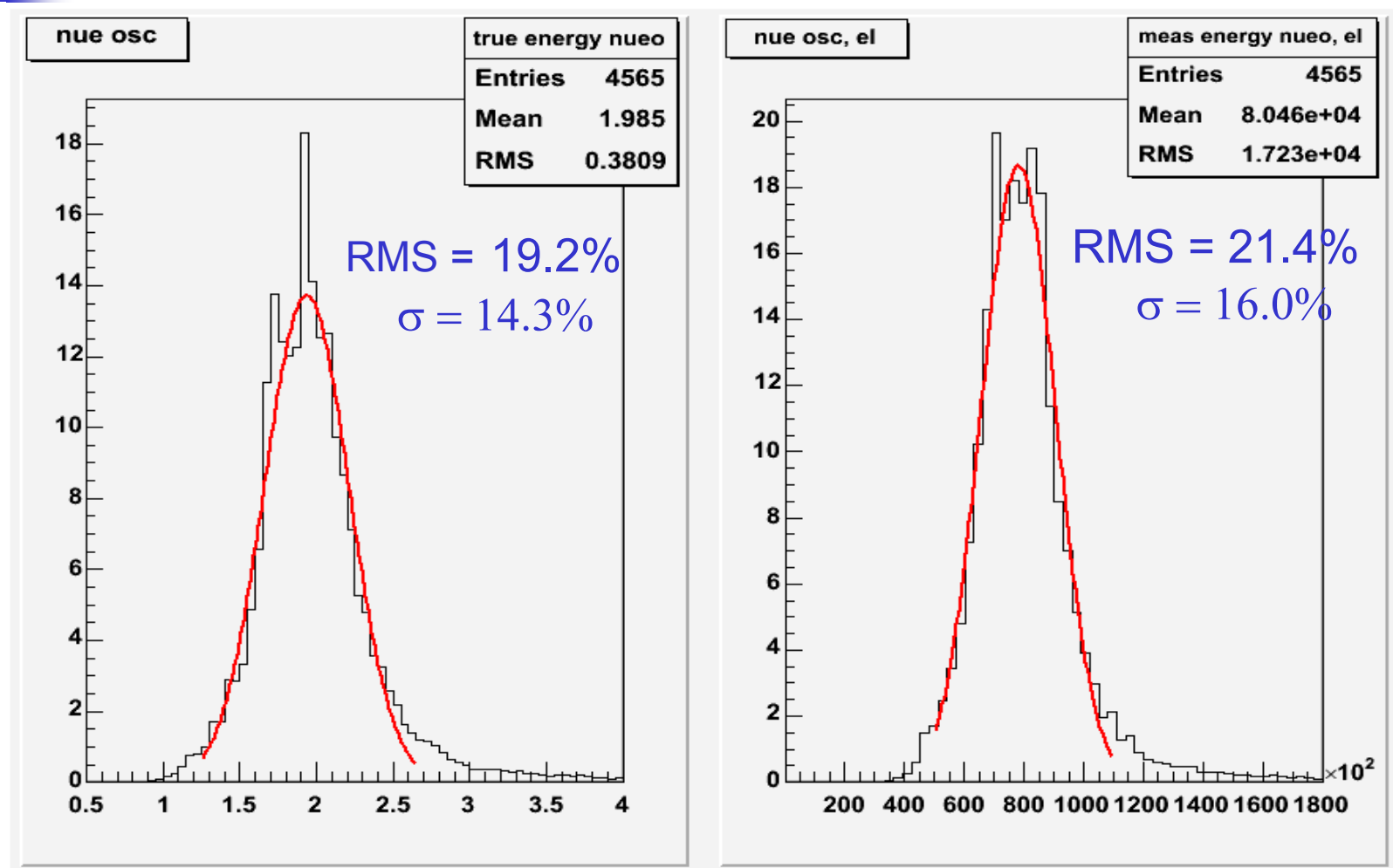
True Energy Distributions



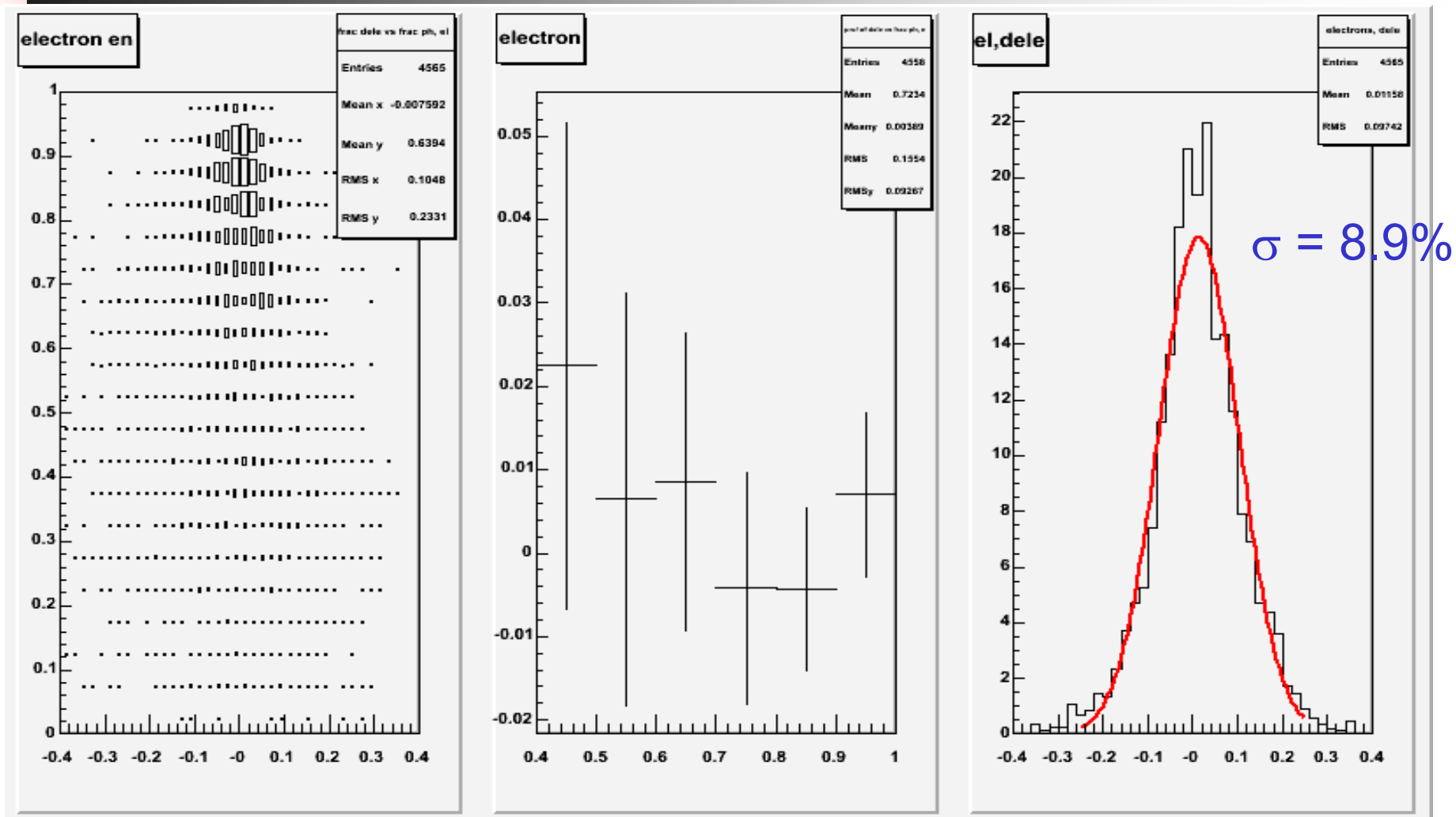
Measured Energy Distributions



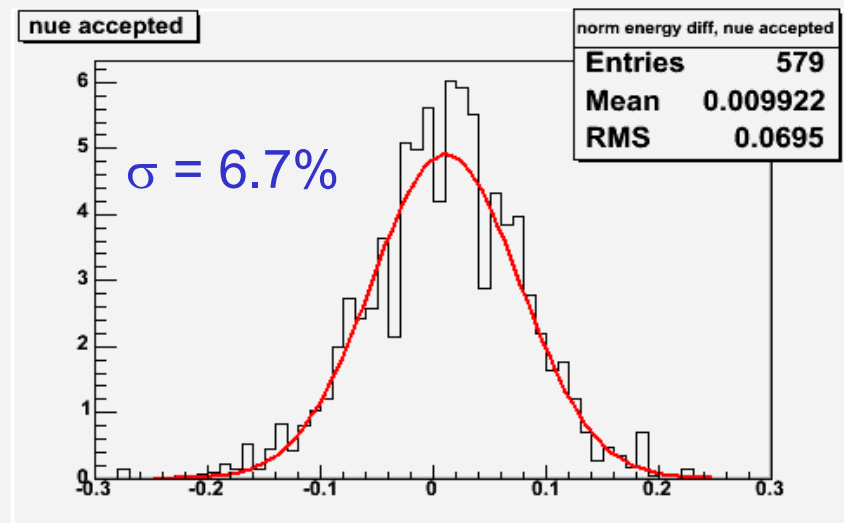
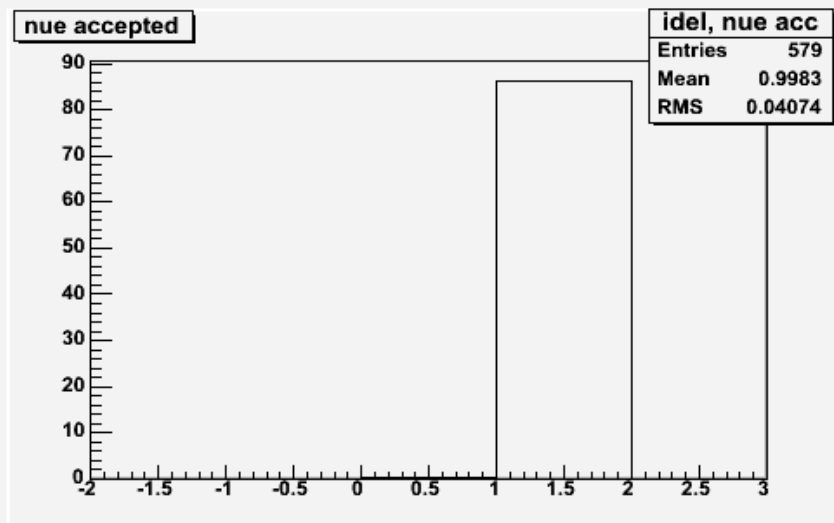
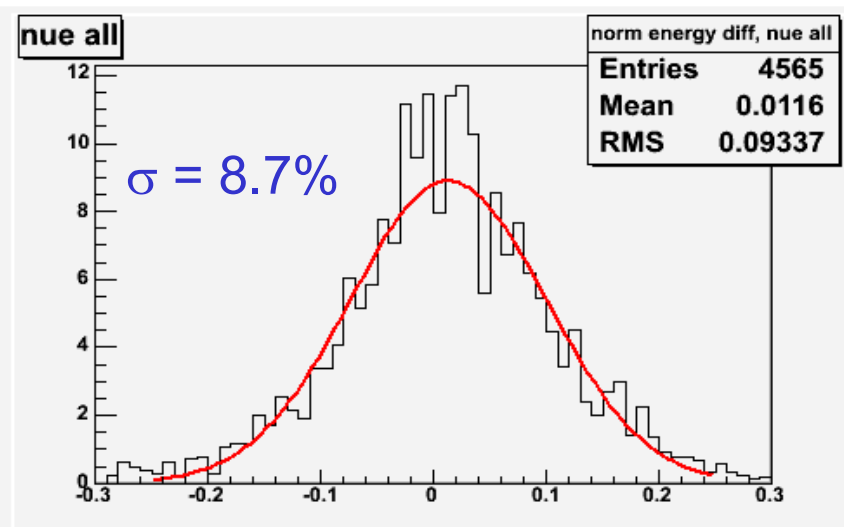
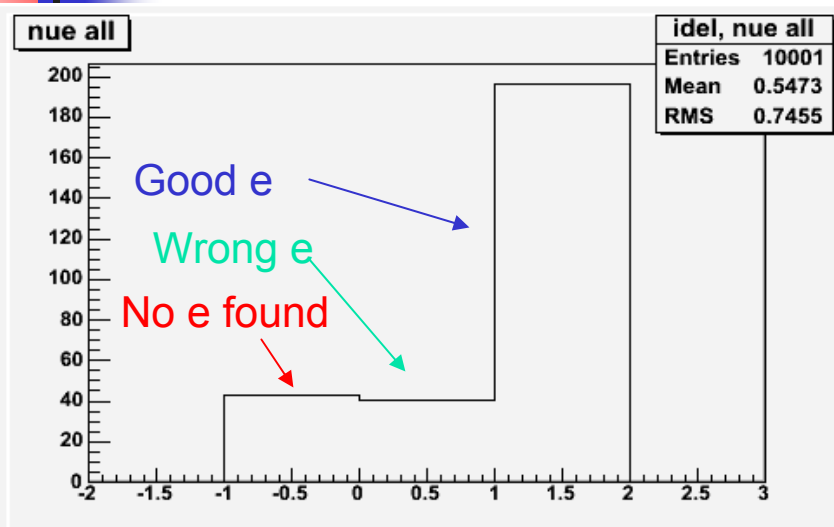
True and measured energies



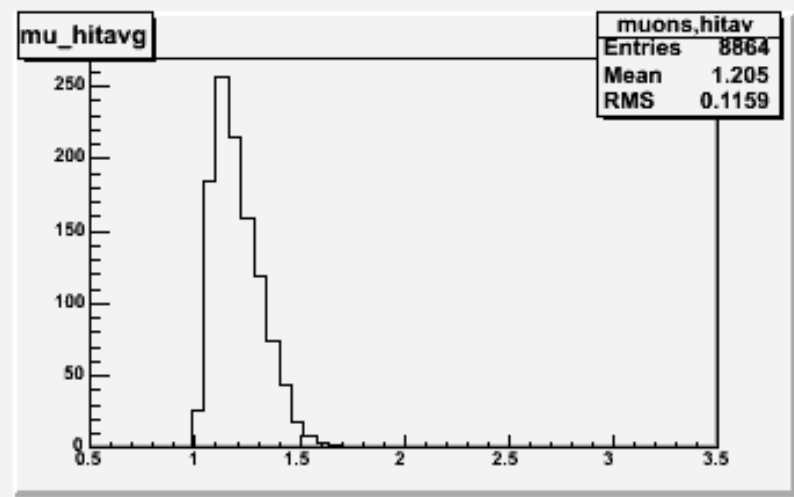
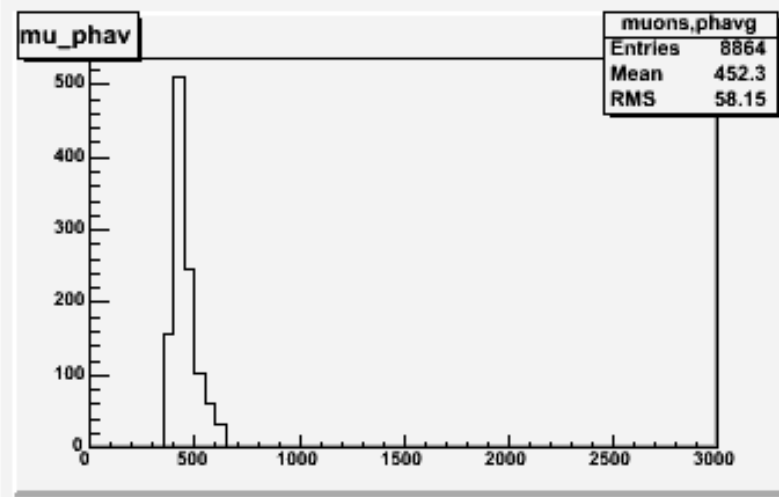
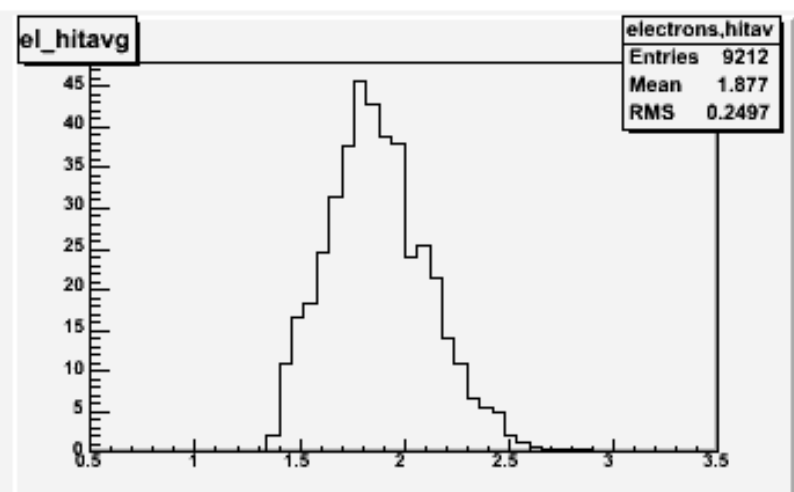
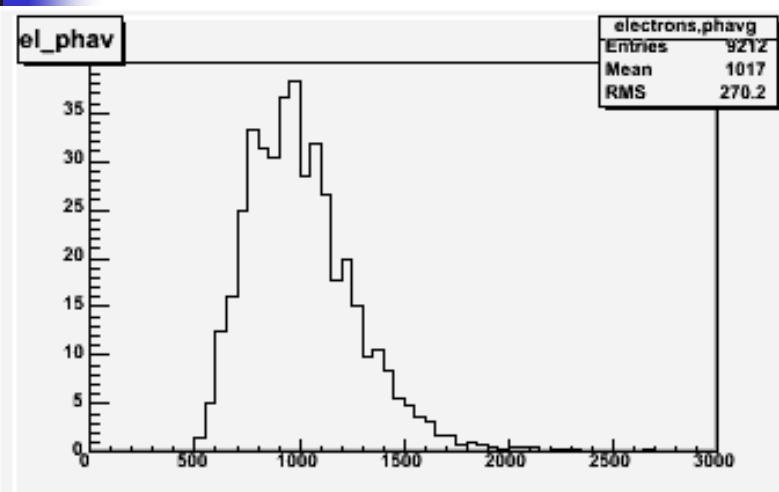
Energy Resolution - 2



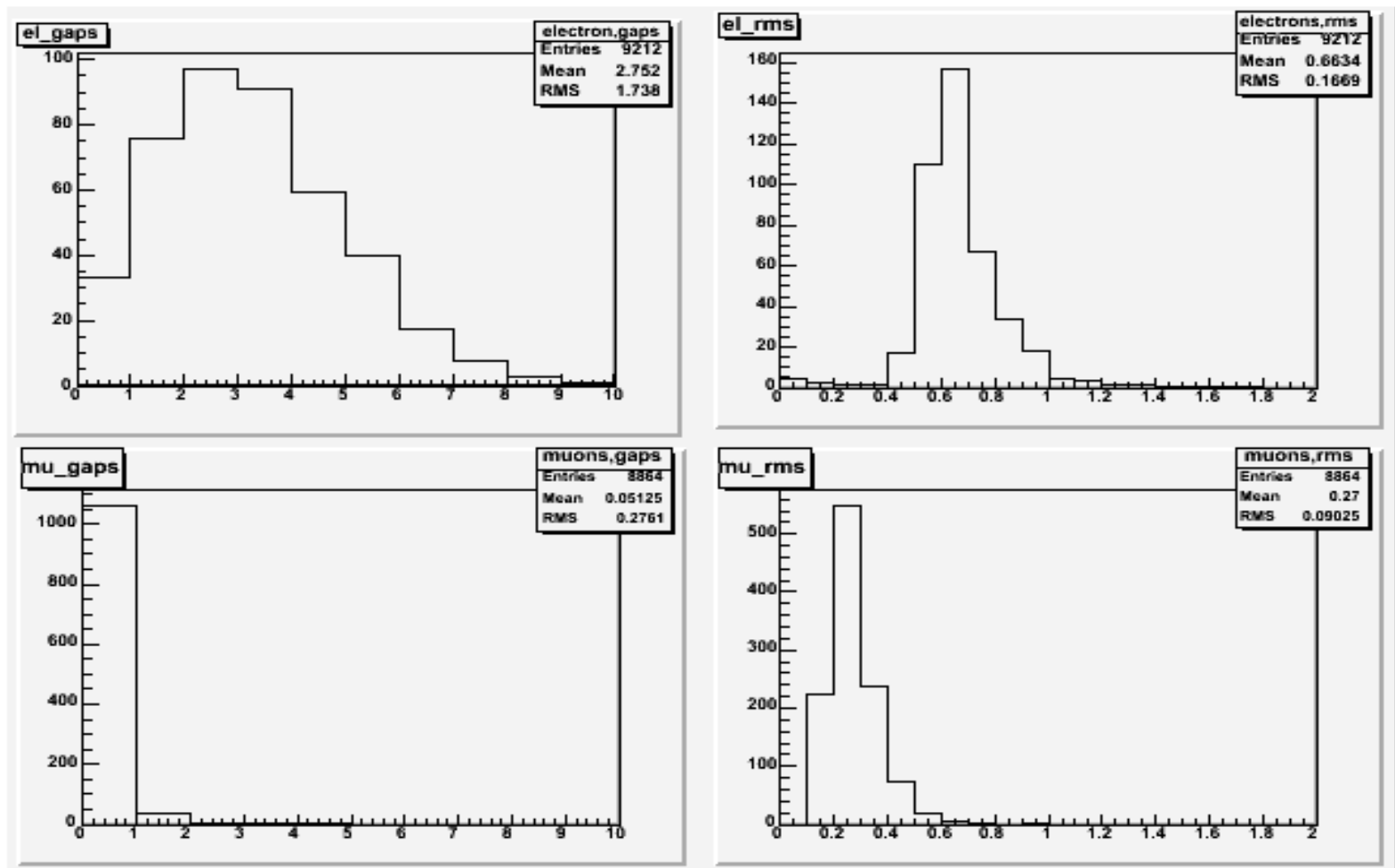
Summary Distributions



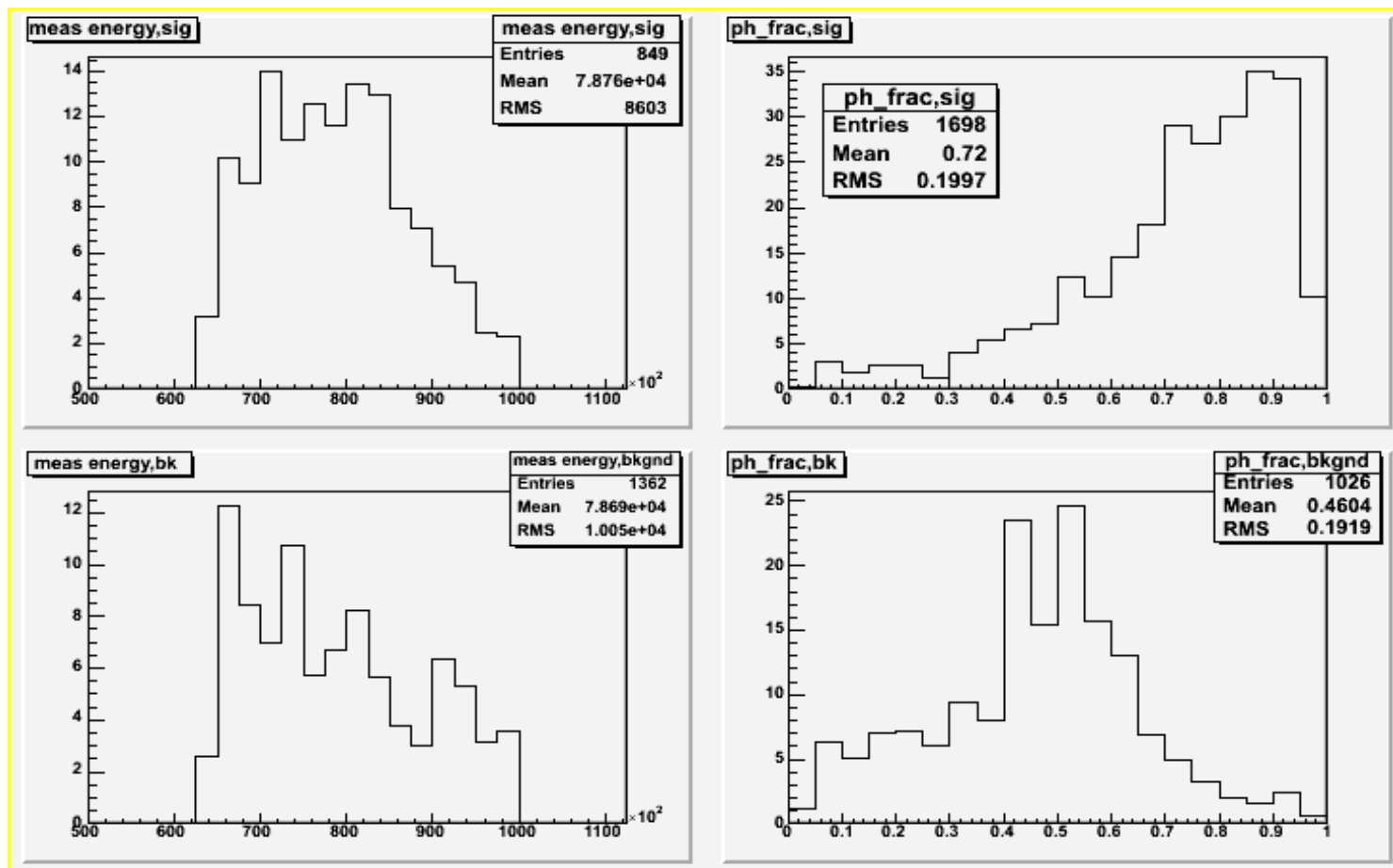
Electron/muon comparison (avg pulse height and no hits)



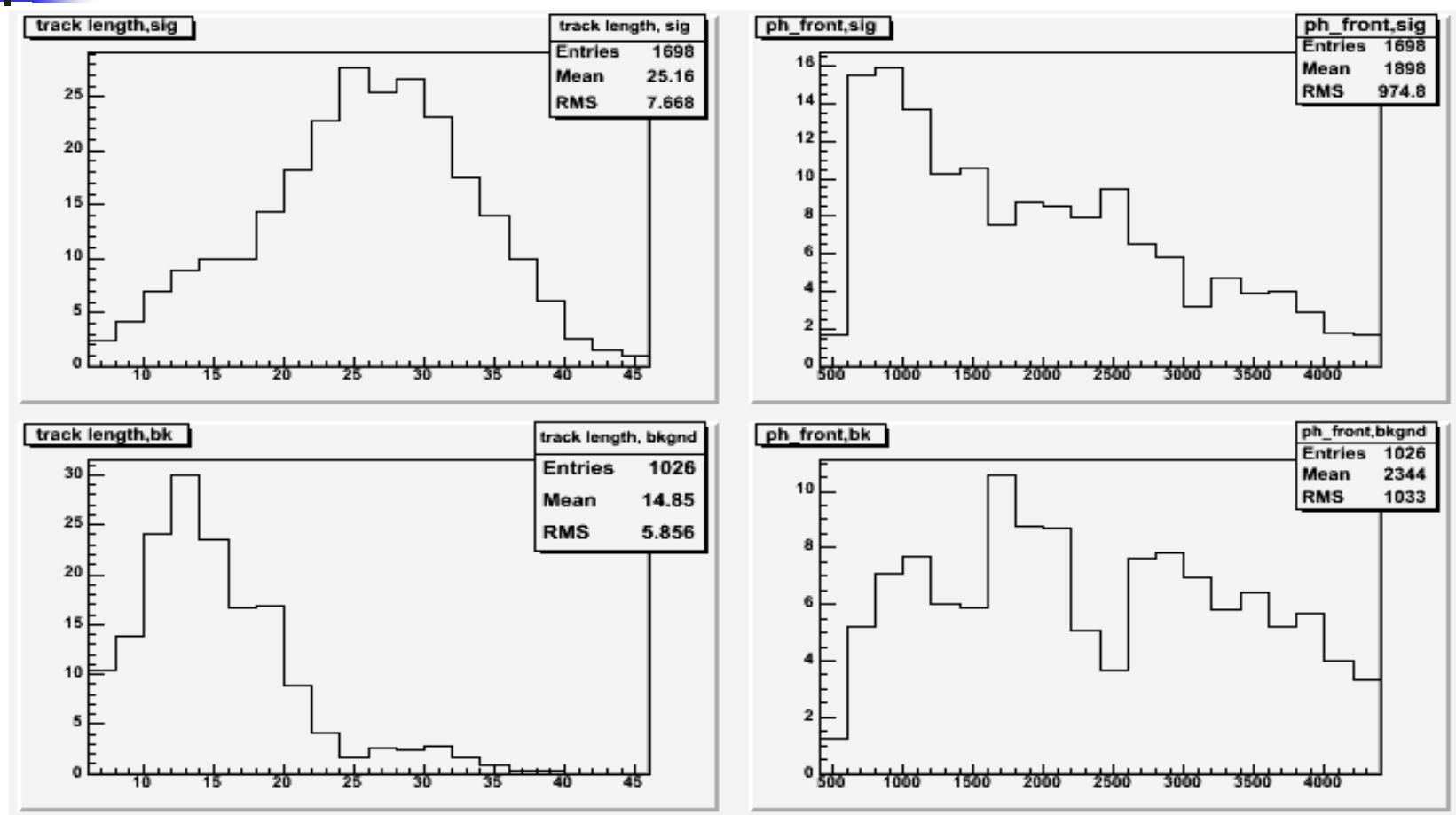
Electron/muon comparison (no of gaps and average rms)



Signal/background (energy and measured “y”)



Signal/background (track length and ph in front)





Simulation Results

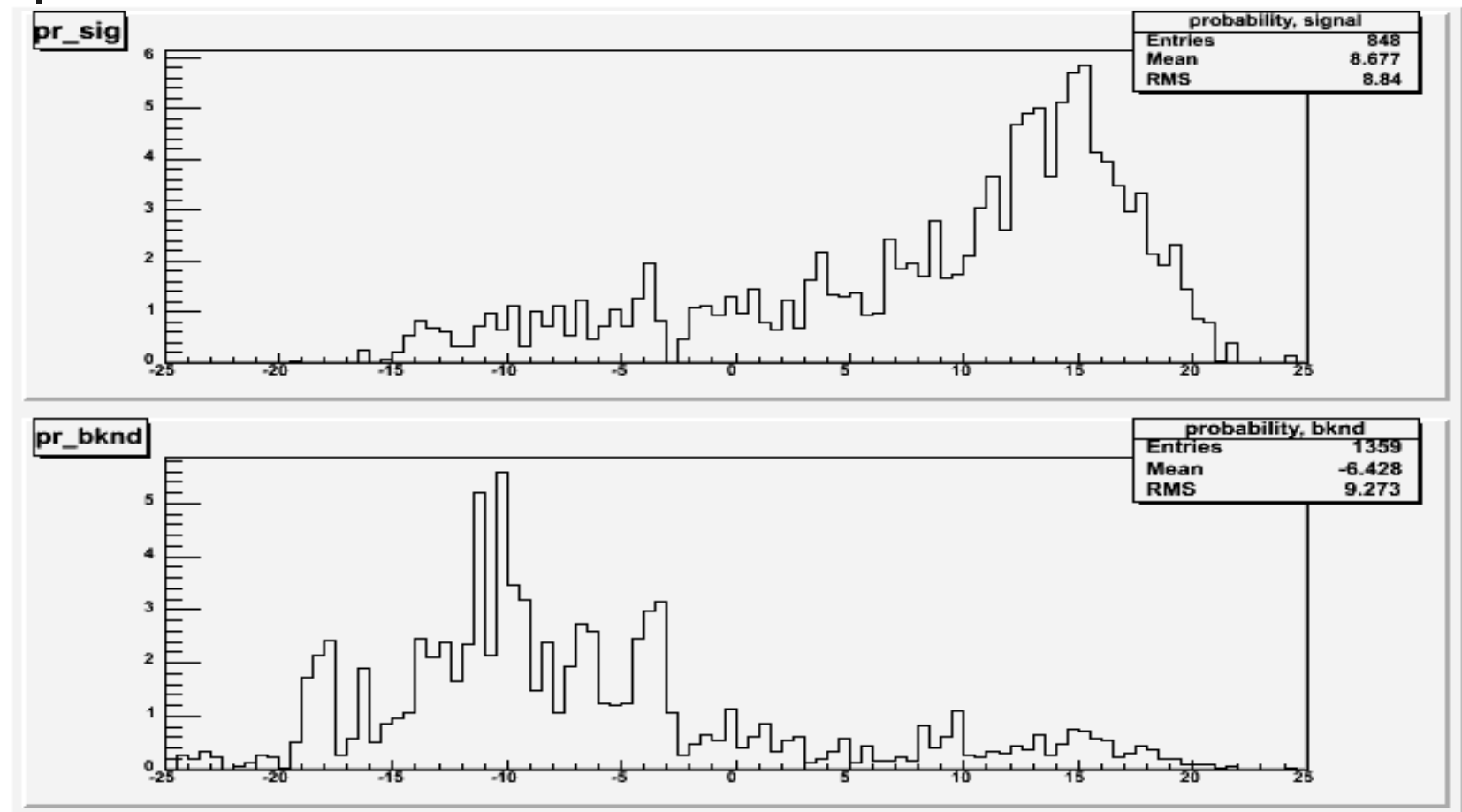
- We show the results of the first simulation for this detector using the method described
- The results have to be considered quite preliminary at this time
- They are based on 10k events for ν_e CC (signal and beam ν_e background), and 10k each for NC ($E_\nu < 6$ GeV), NC (all) and ν_μ CC.



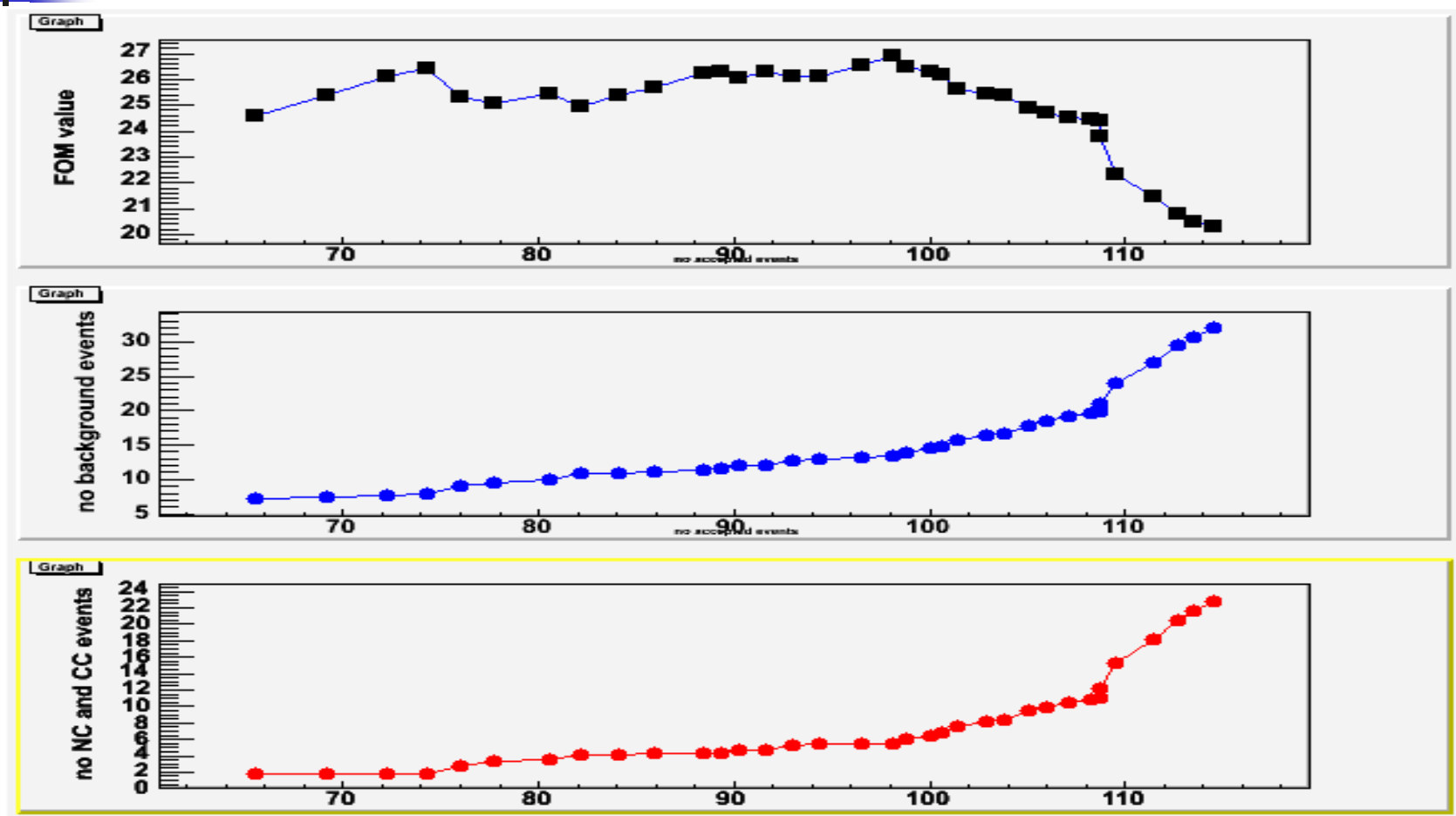
Input Conditions

- Detector 810 km away and at 12 km transverse distance
- Total mass is 25 kt
- Running time is 5 yrs, 3.7×10^{20} ppy
- Latest Messier spectra are used
- “Small” contributions (antineutrinos, NC from ν_e are not included)
- $\Delta m^2_{23} = 2.5 \times 10^{-3} \text{ eV}^2$, $P(\nu_\mu \rightarrow \nu_e) = 0.05$

Signal/background relative probabilities



FOM and backgrounds vs no of signal events





Cuts-only Analysis

SUMMARY OF CUTS

```
total count = 312.857  92.803  1232.33  3569.47  FOM= 4.47185
early cuts, no leak = 176.786  72.305  866.483  3027.41  FOM= 2.80712
electrons, no leak, early cuts = 176.786  49.0402  113.258  565.93  FOM= 6.5511
electrons, + energy cut = 140.047  13.5834  48.8582  168.928  FOM= 9.20708
no coherent = 140.047  13.5834  48.8582  168.928  FOM= 9.20708
no muons = 139.491  13.3785  37.4855  166.584  FOM= 9.45952
no gammas = 132.657  12.4862  32.2736  145.547  FOM= 9.61622
+ dist from vtx, gaps nr vtx = 120.291  10.8391  20.1878  97.9566  FOM= 10.5
917
+ track length = 116.291  9.96149  13.2482  55.3218  FOM= 13.1227
+ avg ph = 114.464  9.77663  10.8854  49.18  FOM= 13.6966
+ ph frac = 101.967  8.16796  4.46897  14.9083  FOM= 19.4284
+ curvature, asymm = 90.6567  7.27035  2.35719  6.84207  FOM= 22.3387
+ ph_front, ph_unusd = 86.3847  7.02798  0.945093  6.03828  FOM= 23.0779
+ quasielastics = 86.3847  7.02798  0.945093  6.21868  FOM= 22.9308
```



Possible Future Improvements

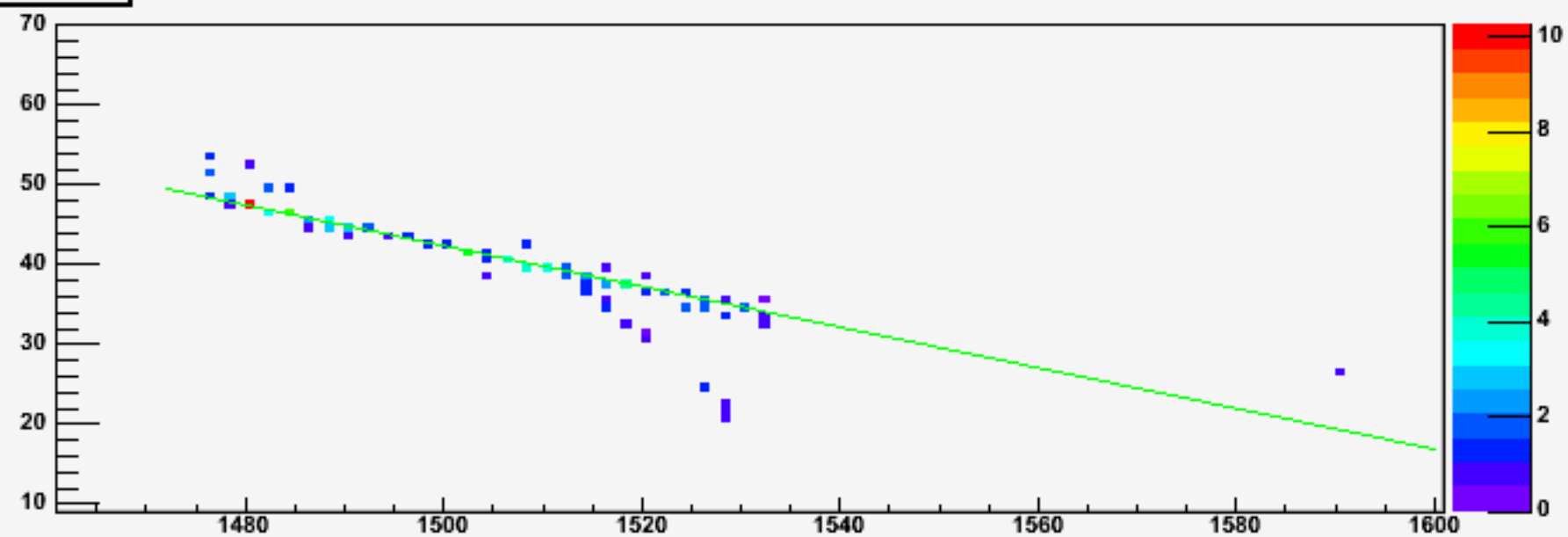
- Take account of inert material
- More sophisticated method of selecting electron (if >1 candidate)
- More sophisticated γ definition and its use
- Better track reconstruction (see sample of events to follow)
- Use of correlated distributions in ML and/or possibly neural network
- An alternative, more sophisticated, approach to pattern recognition



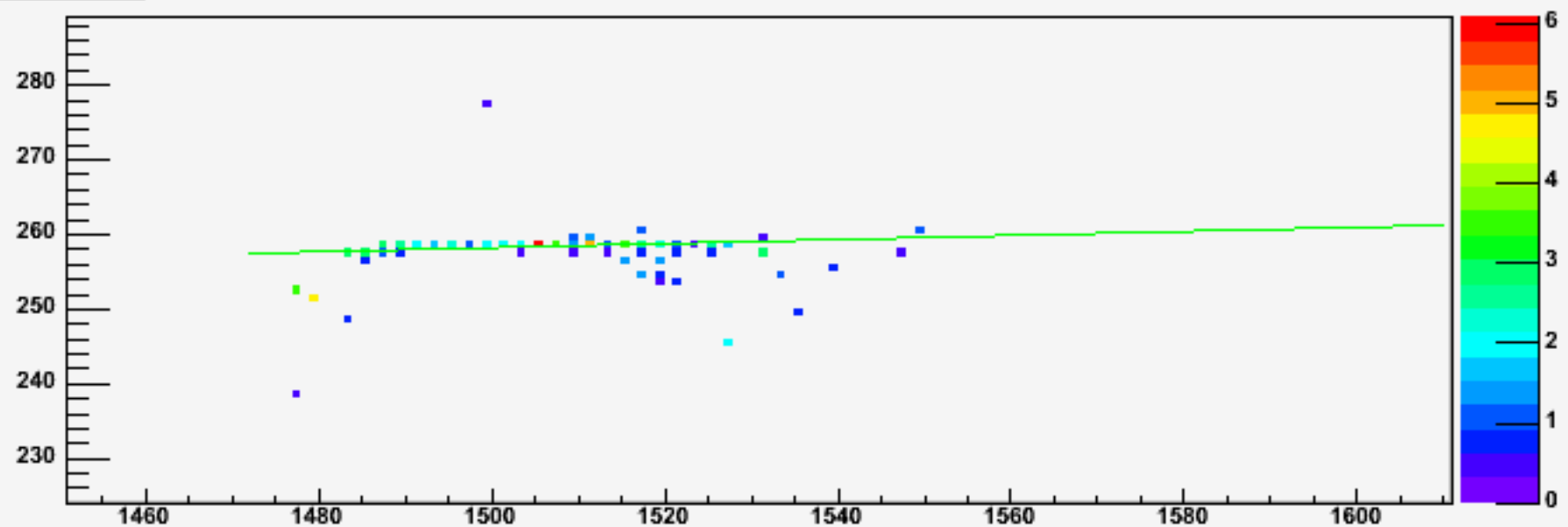
Examples of Events

- We first show some NC and ν_μ CC events which pass our cuts
- Bear in mind that these are roughly 1 per mil
- Then we shall show ν_e CC events in the energy range of interest which fail in reconstruction (no electron found)
- These are relatively typical; chosen only to demonstrate different categories of failures

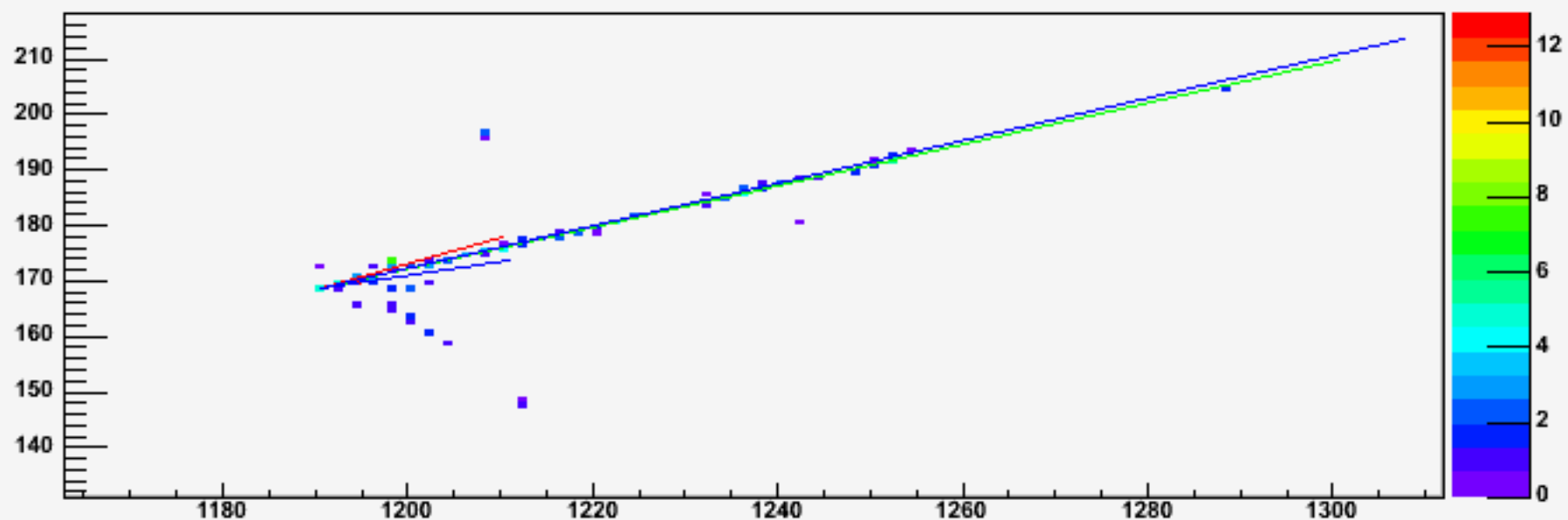
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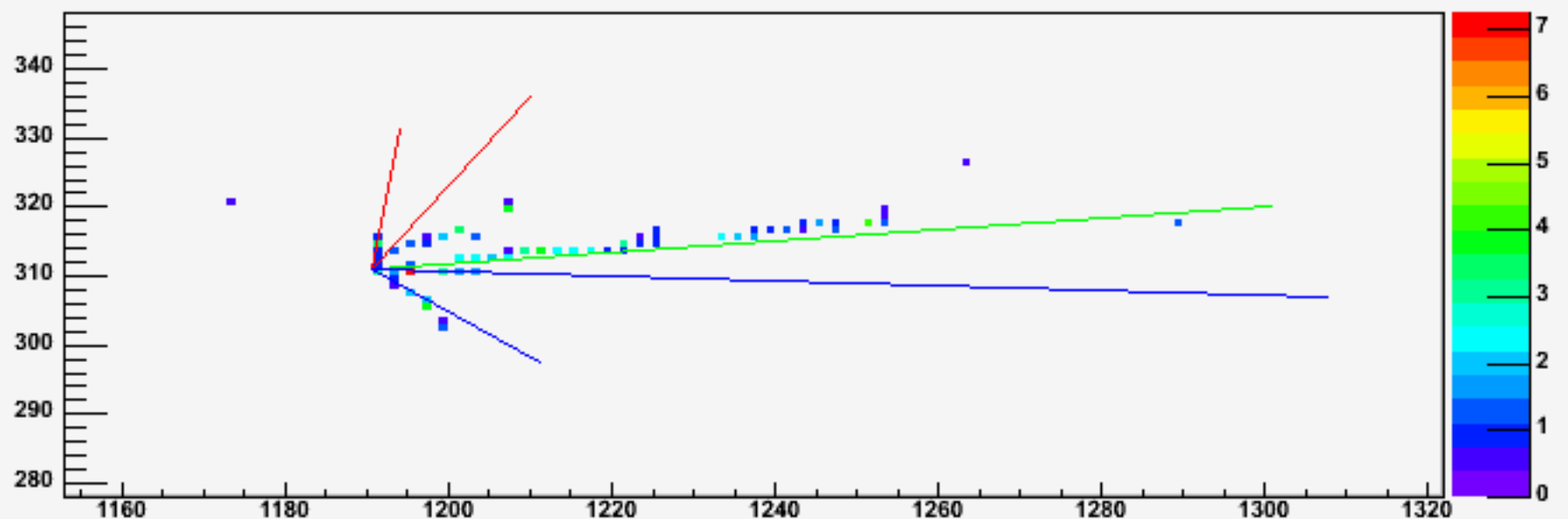
YStripVsPlane



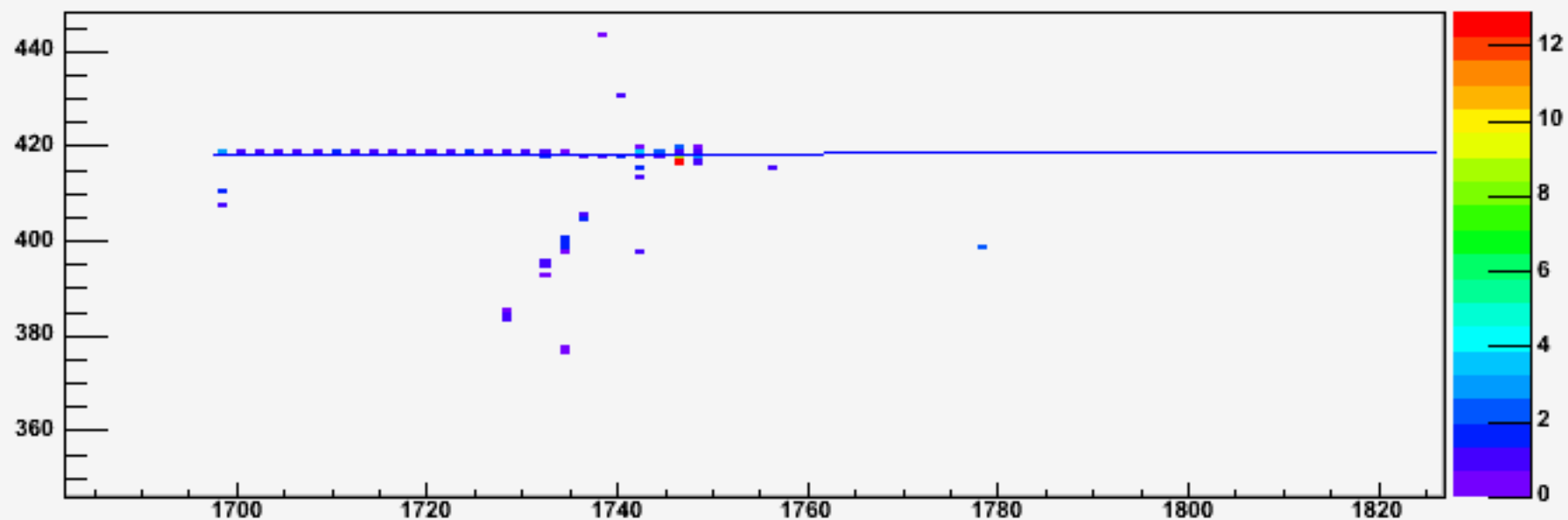
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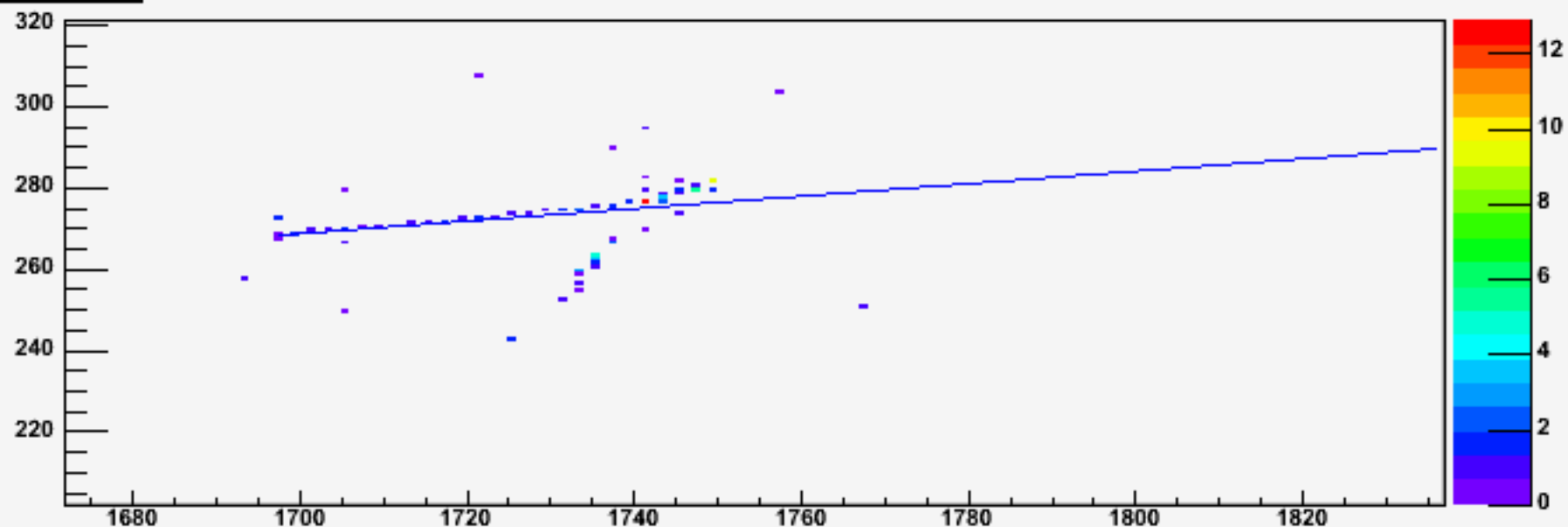
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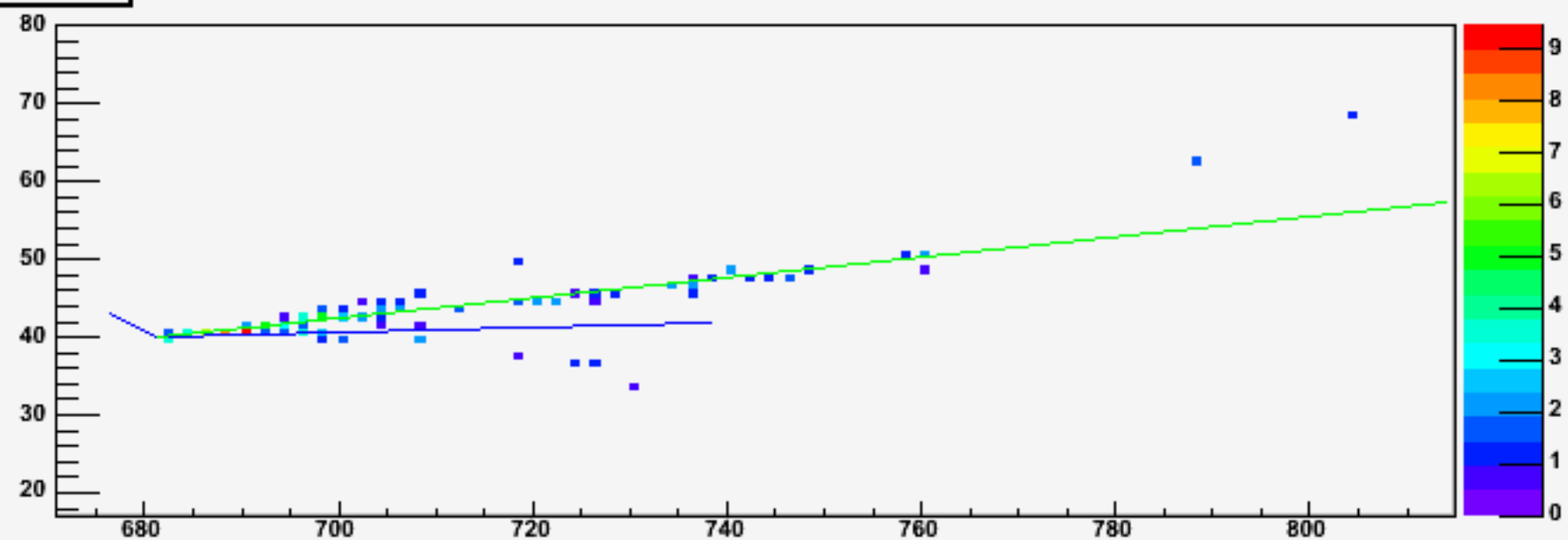
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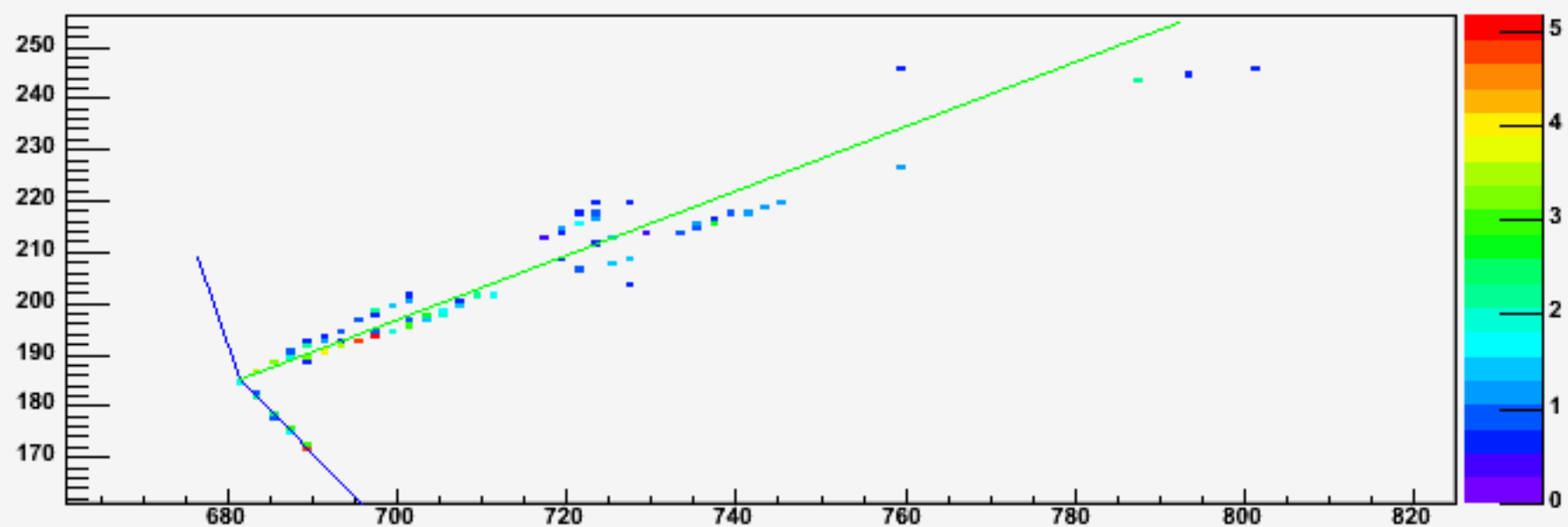
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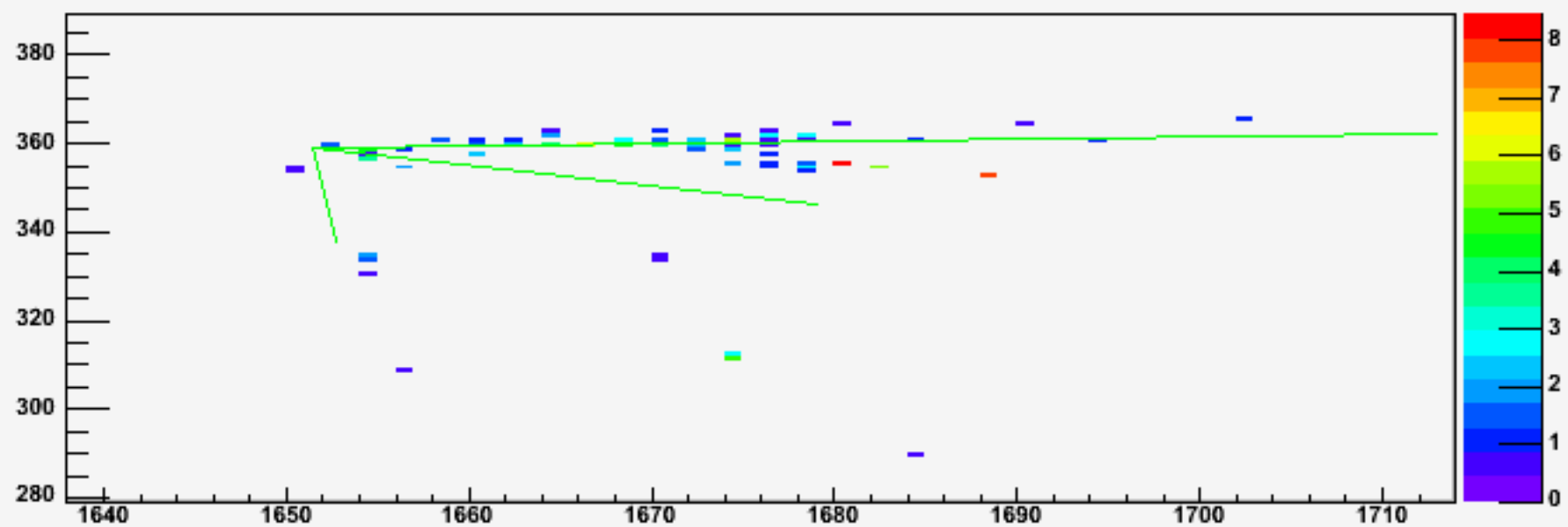
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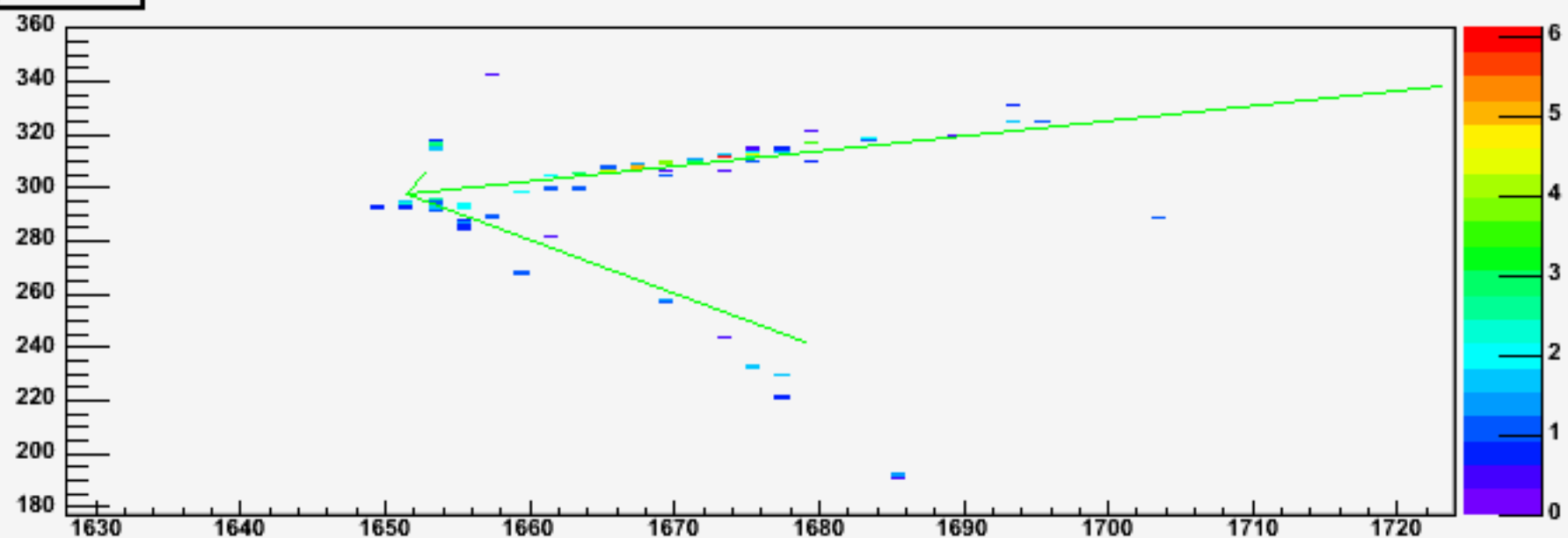
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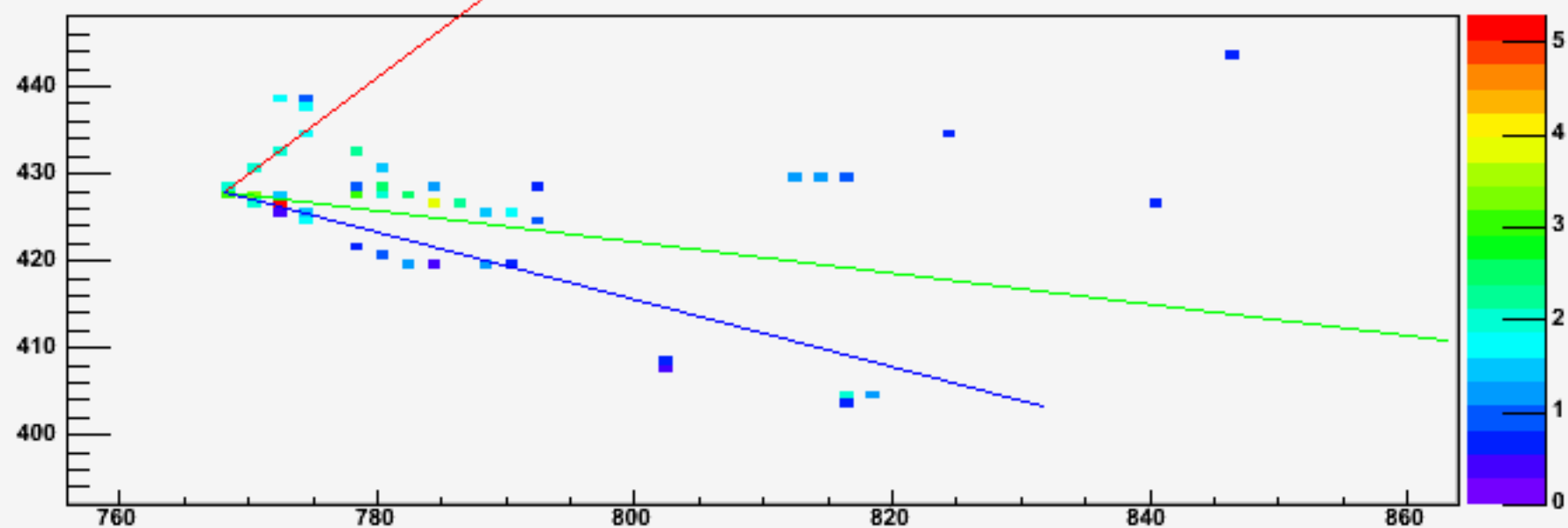
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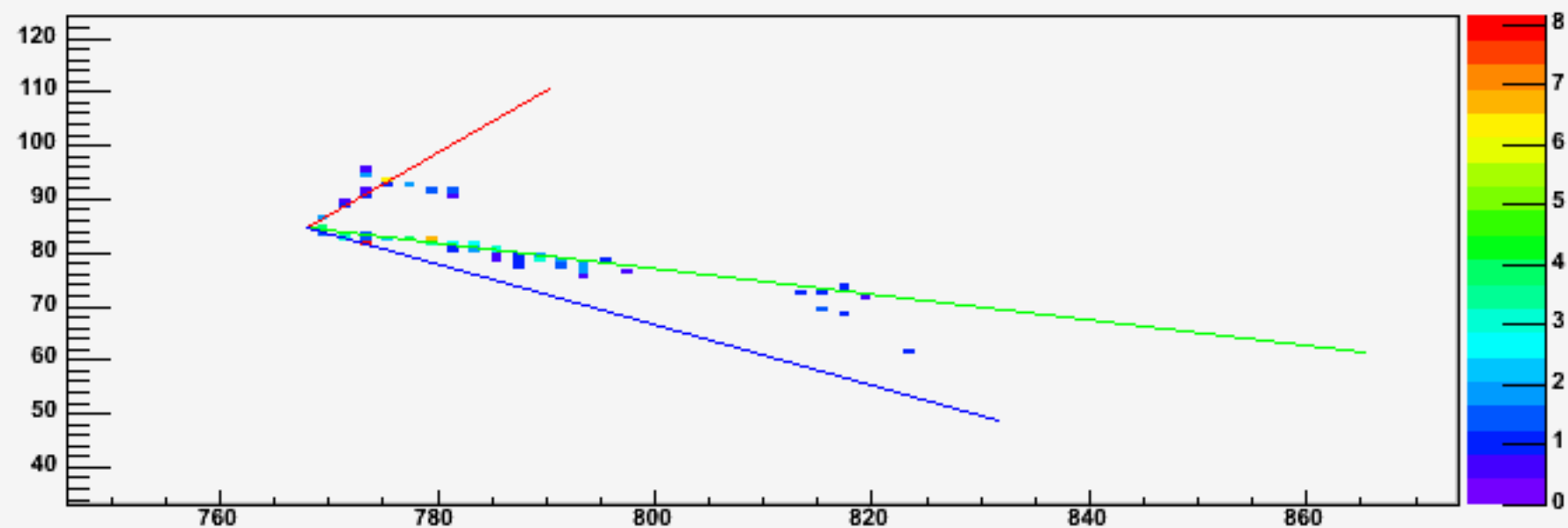
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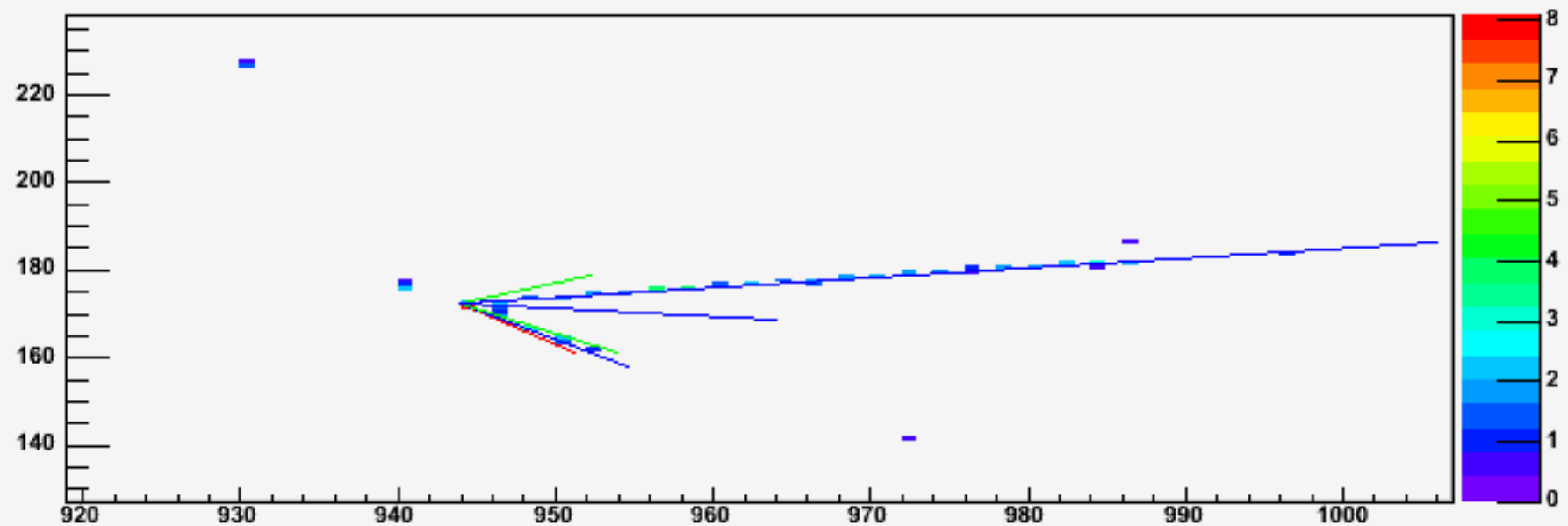
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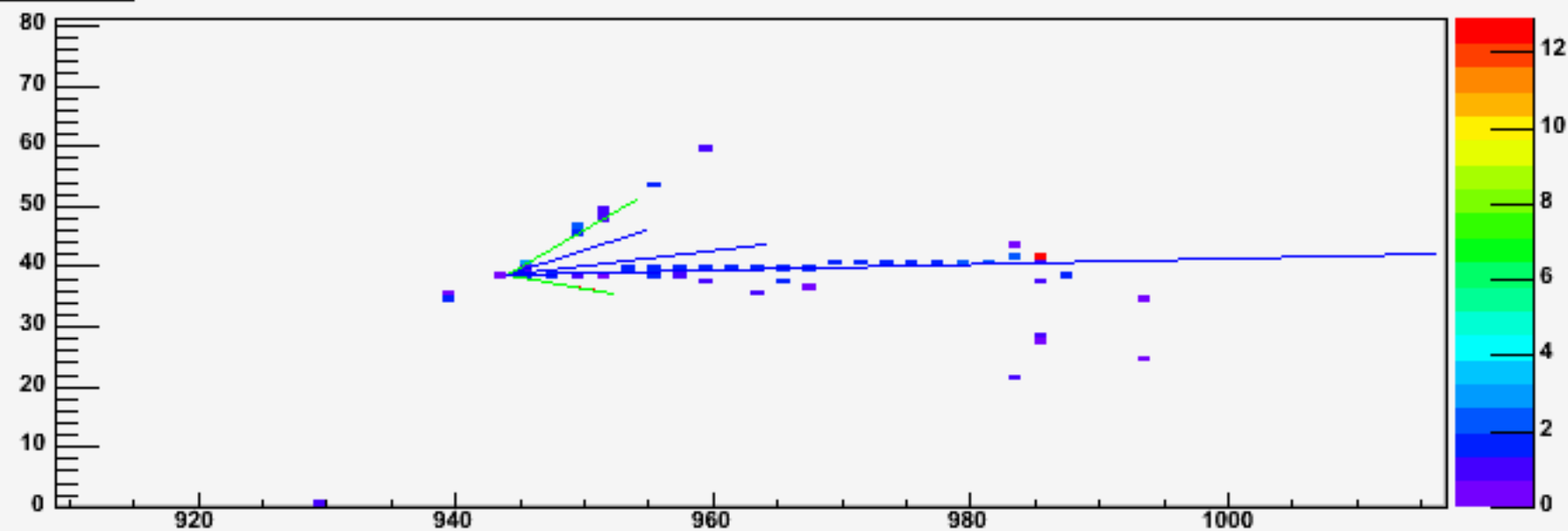
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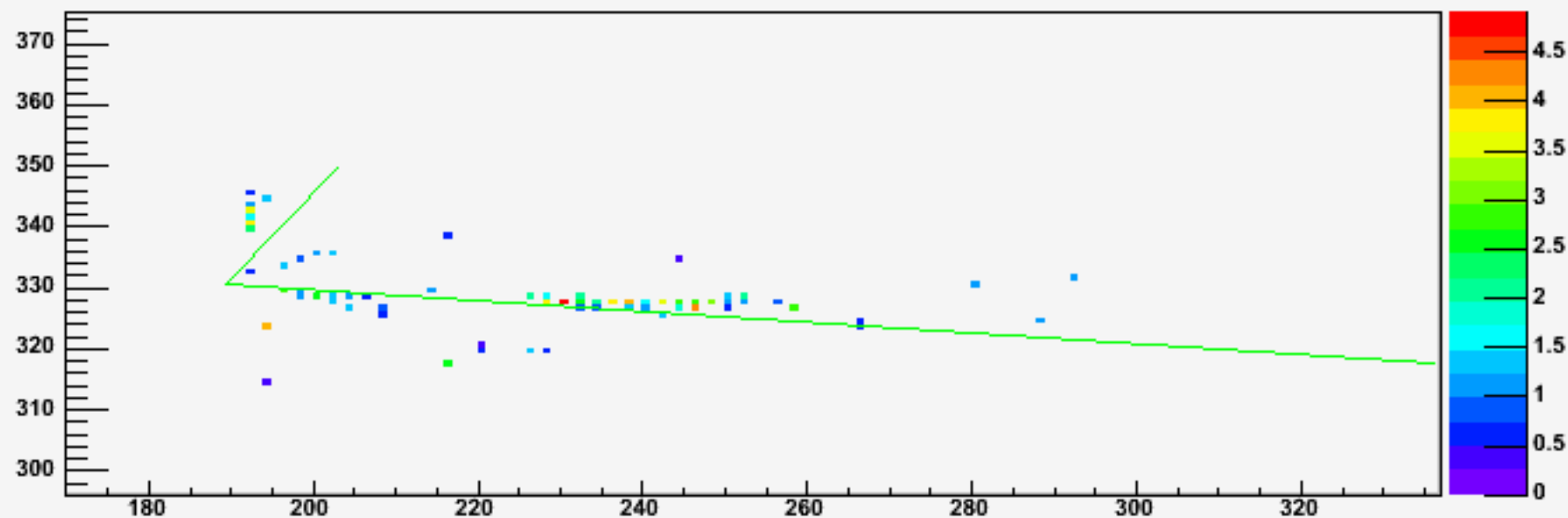
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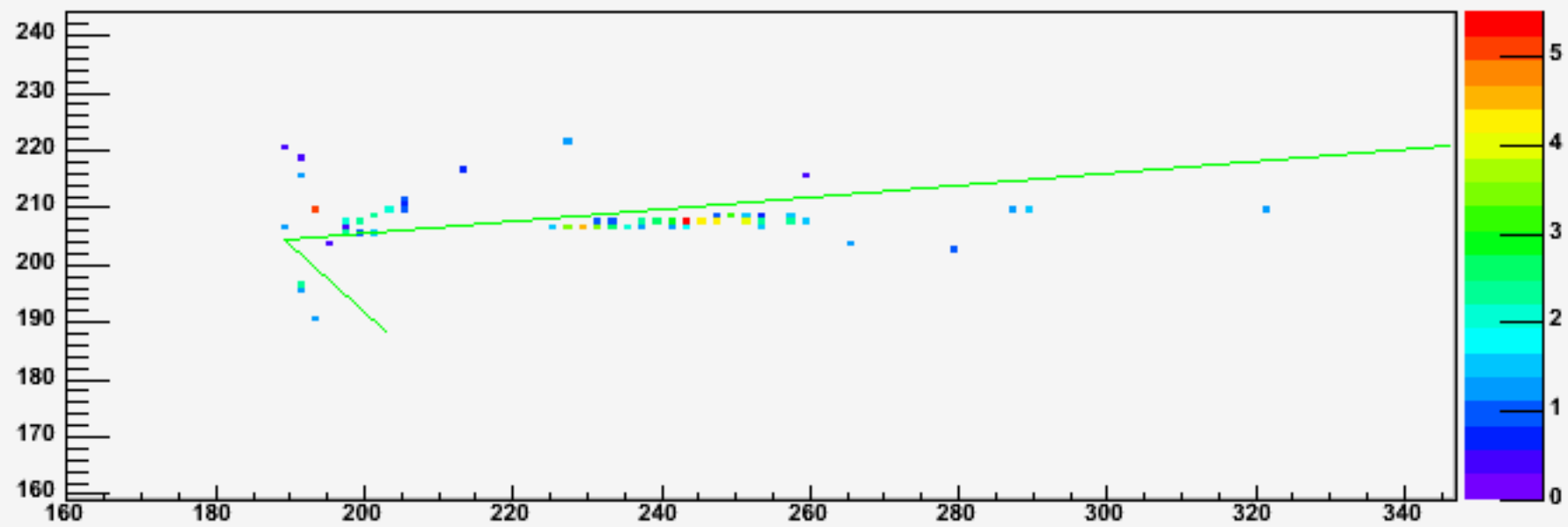
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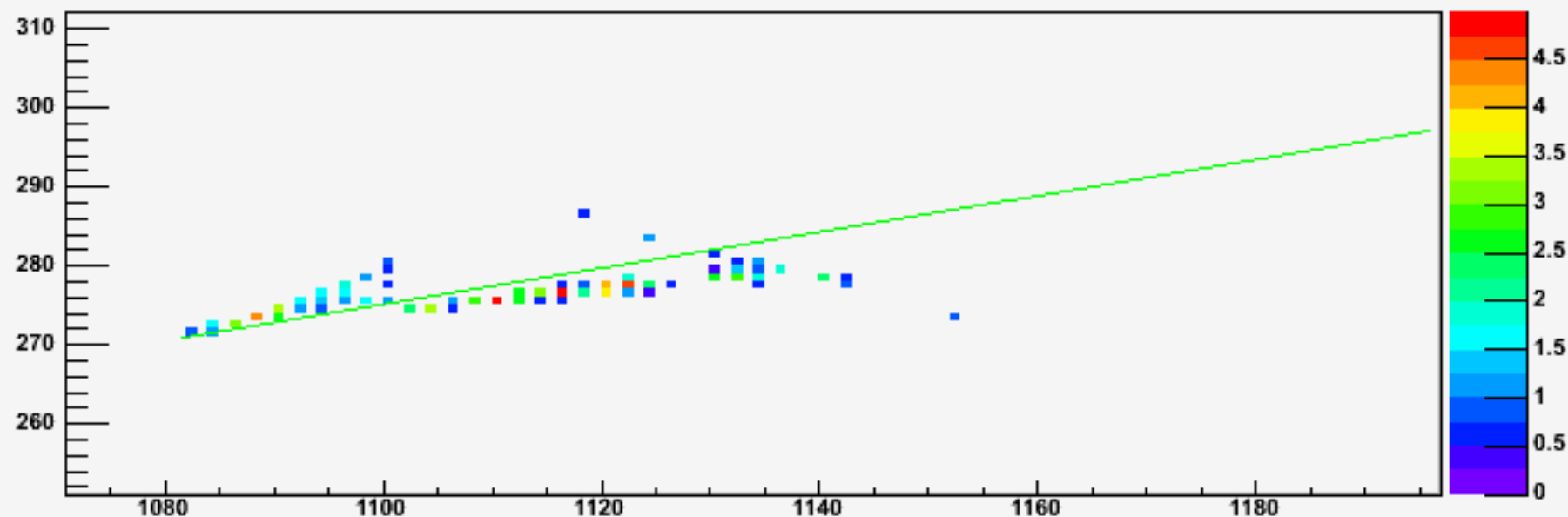
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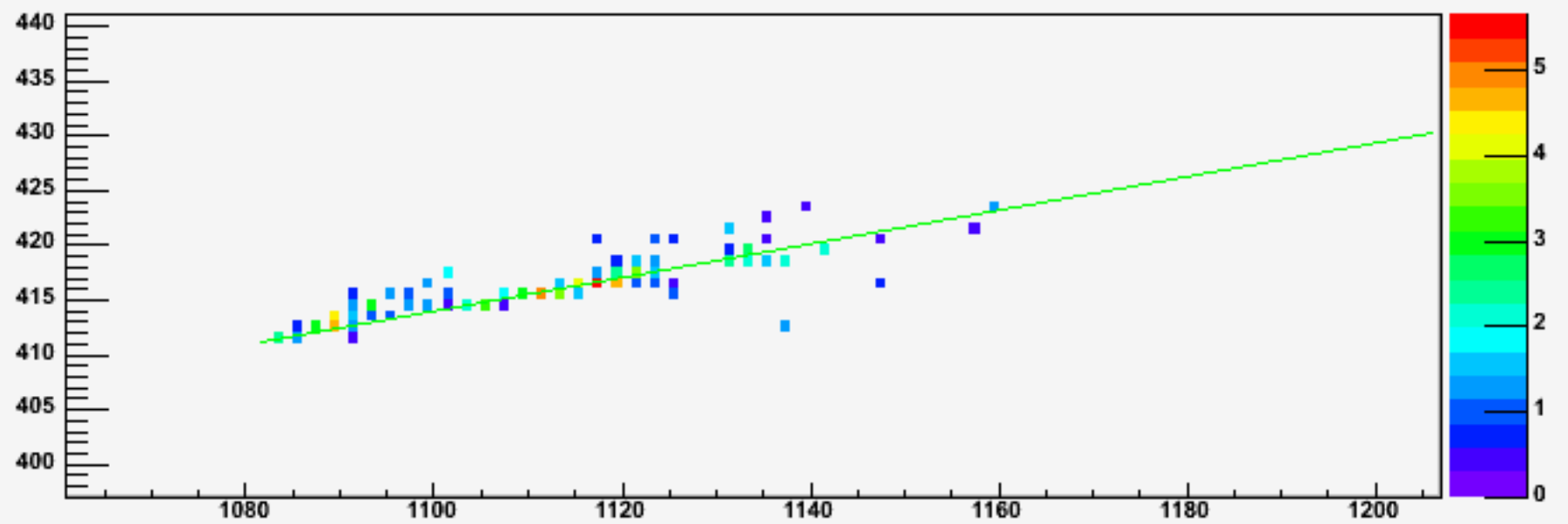
YStripVsPlane



XStripVsPlane

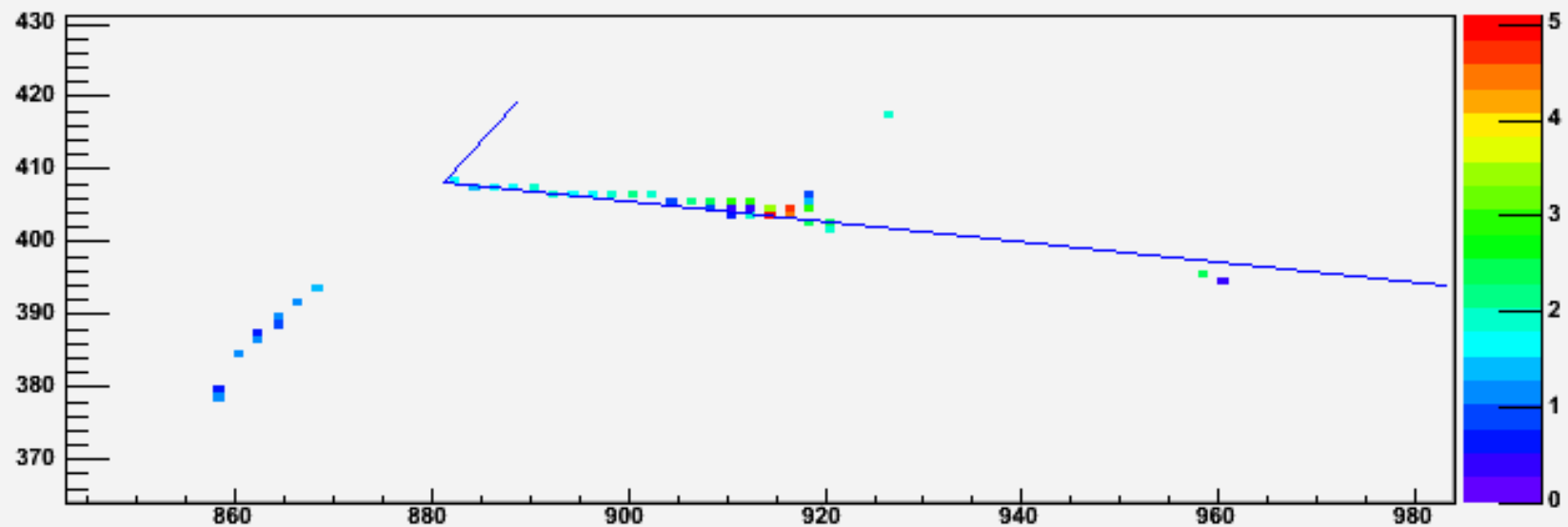


YStripVsPlane

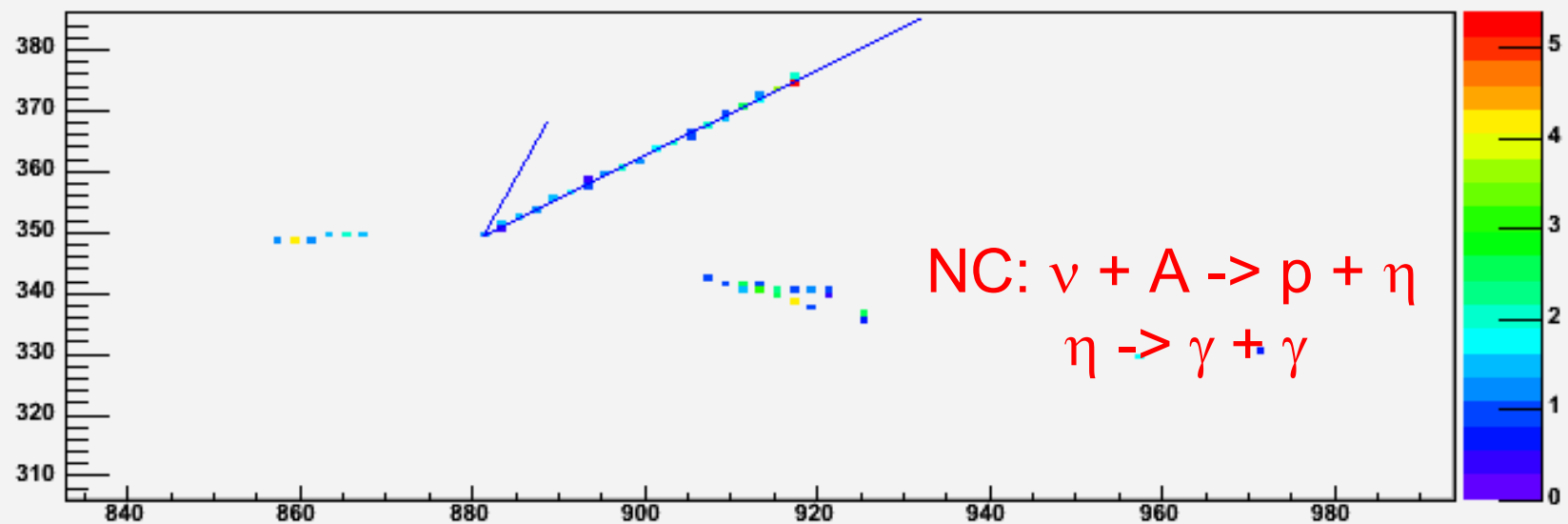


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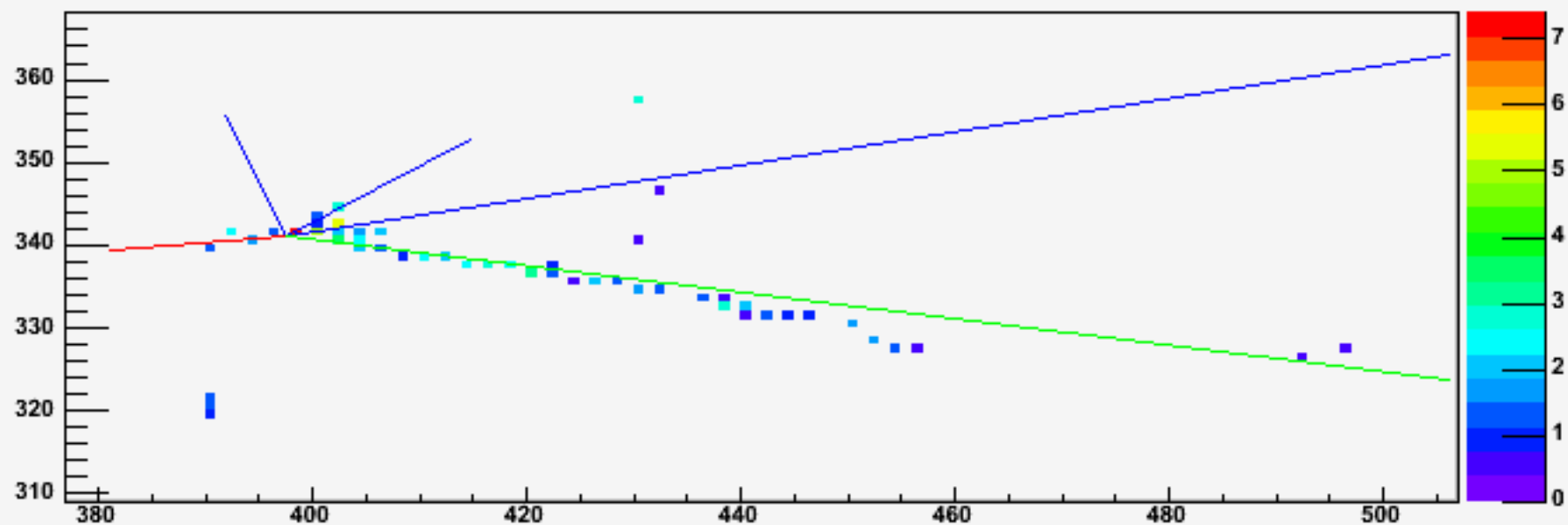
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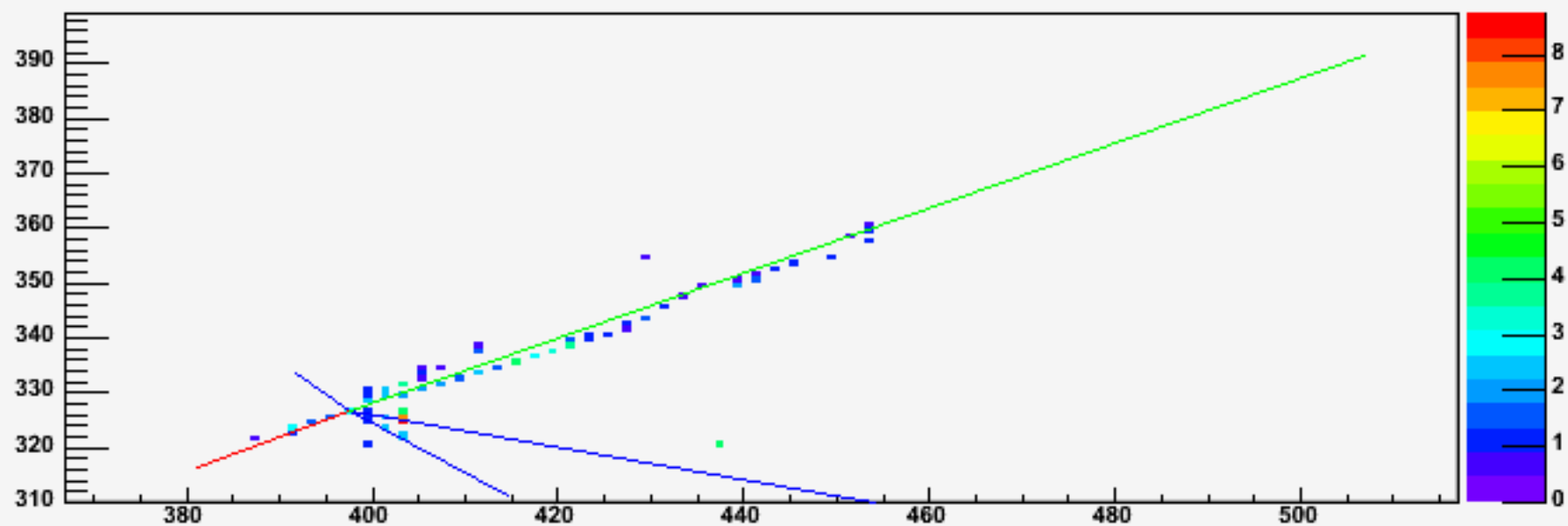
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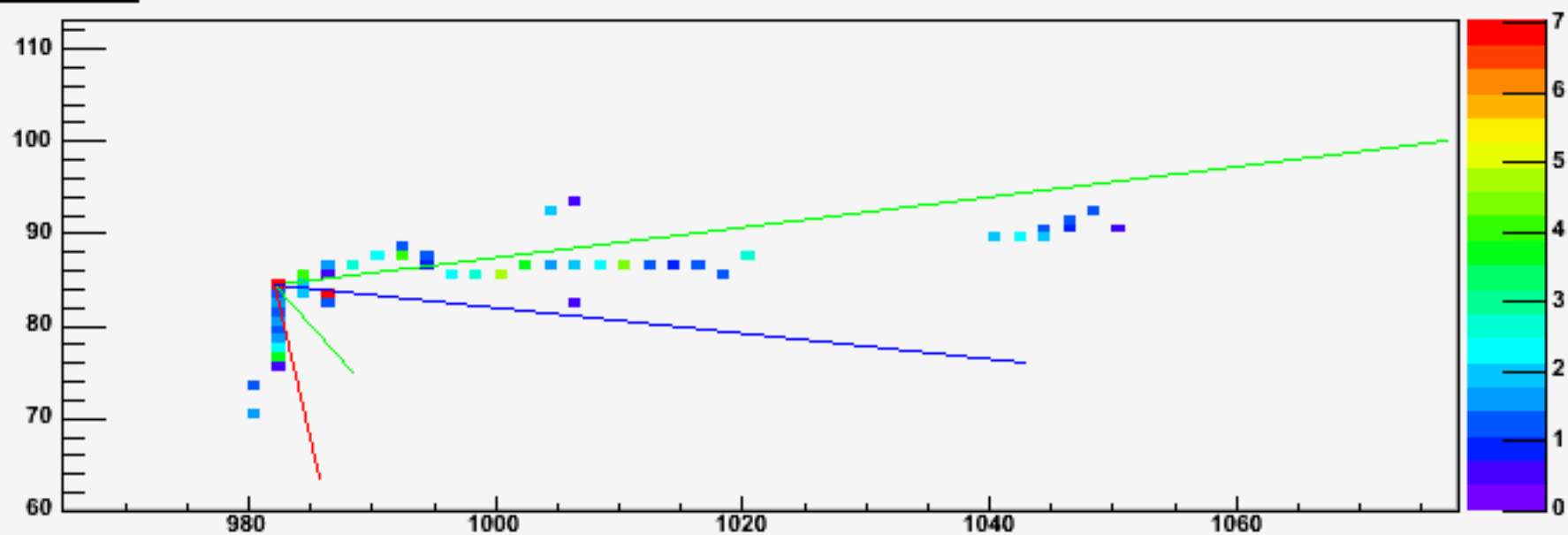
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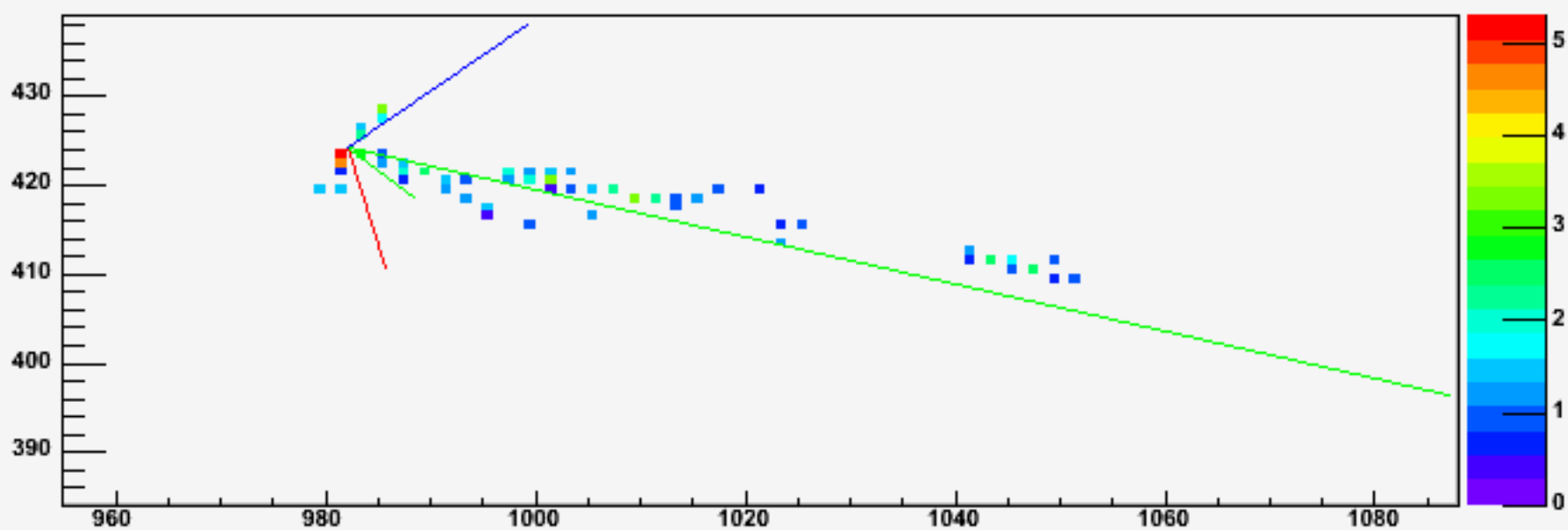
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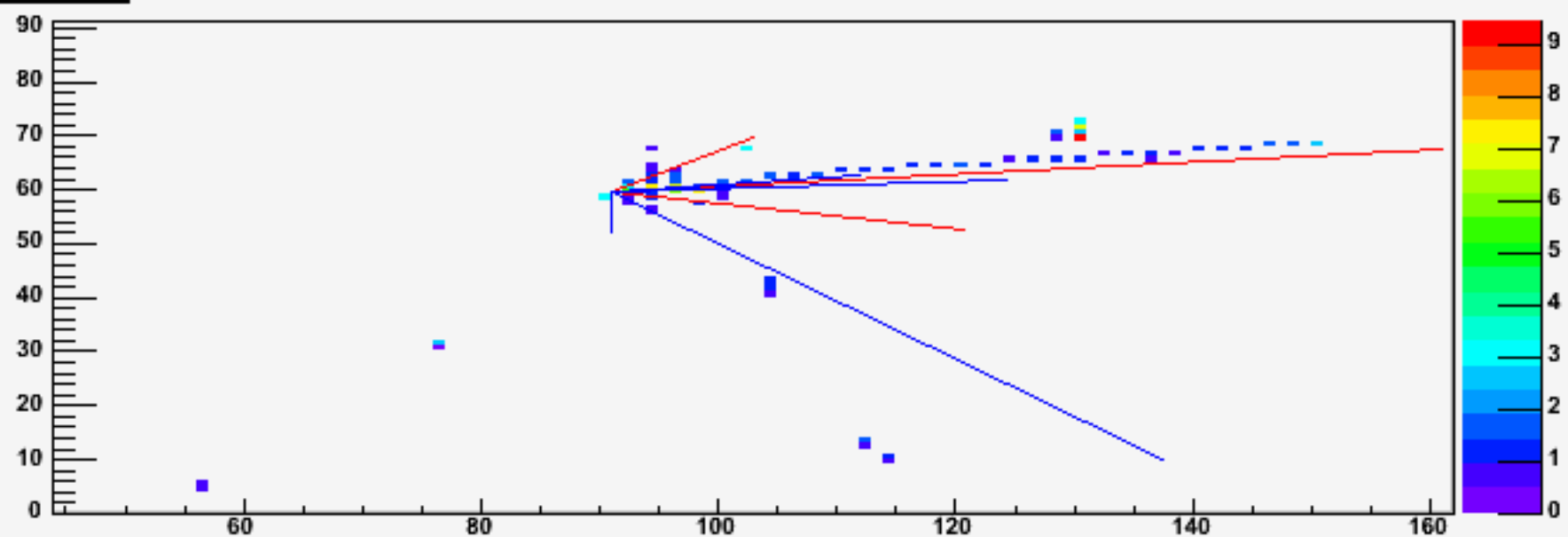
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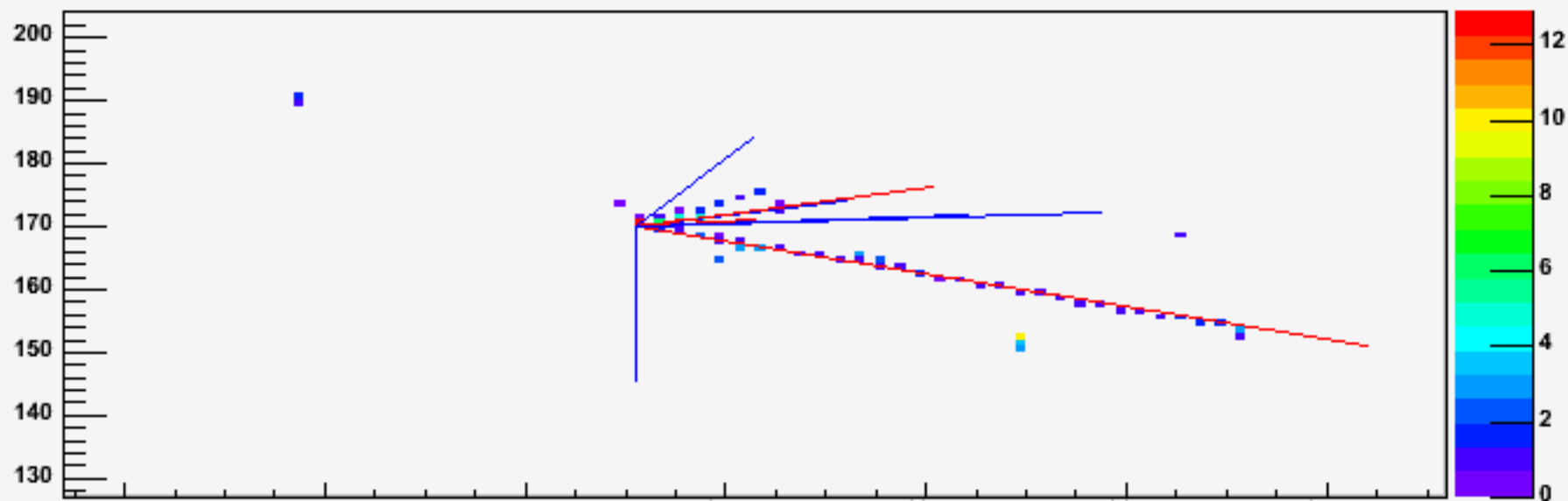
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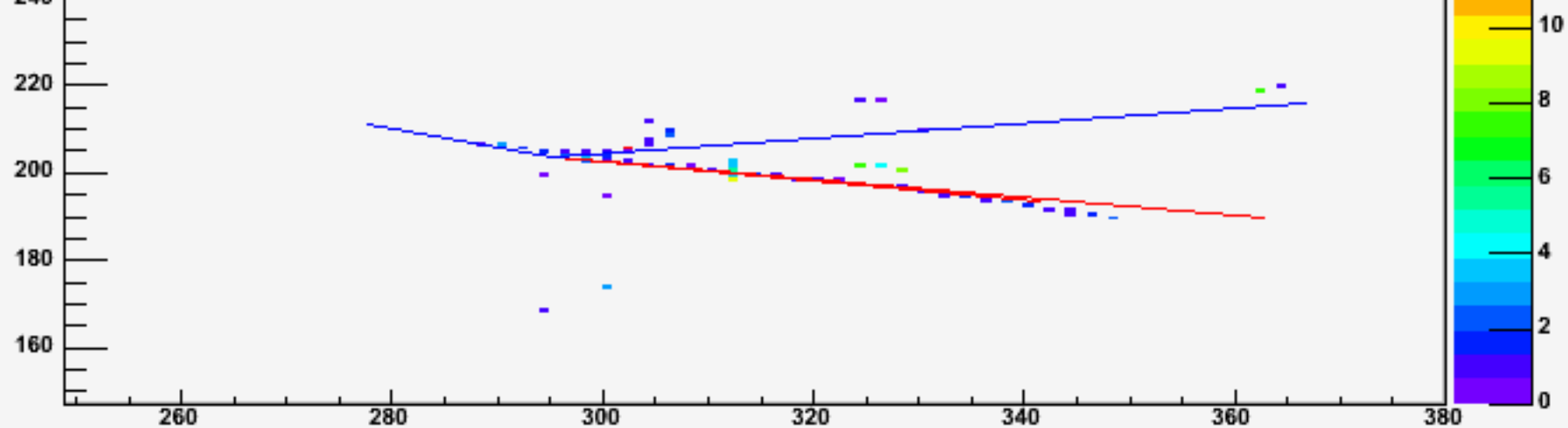


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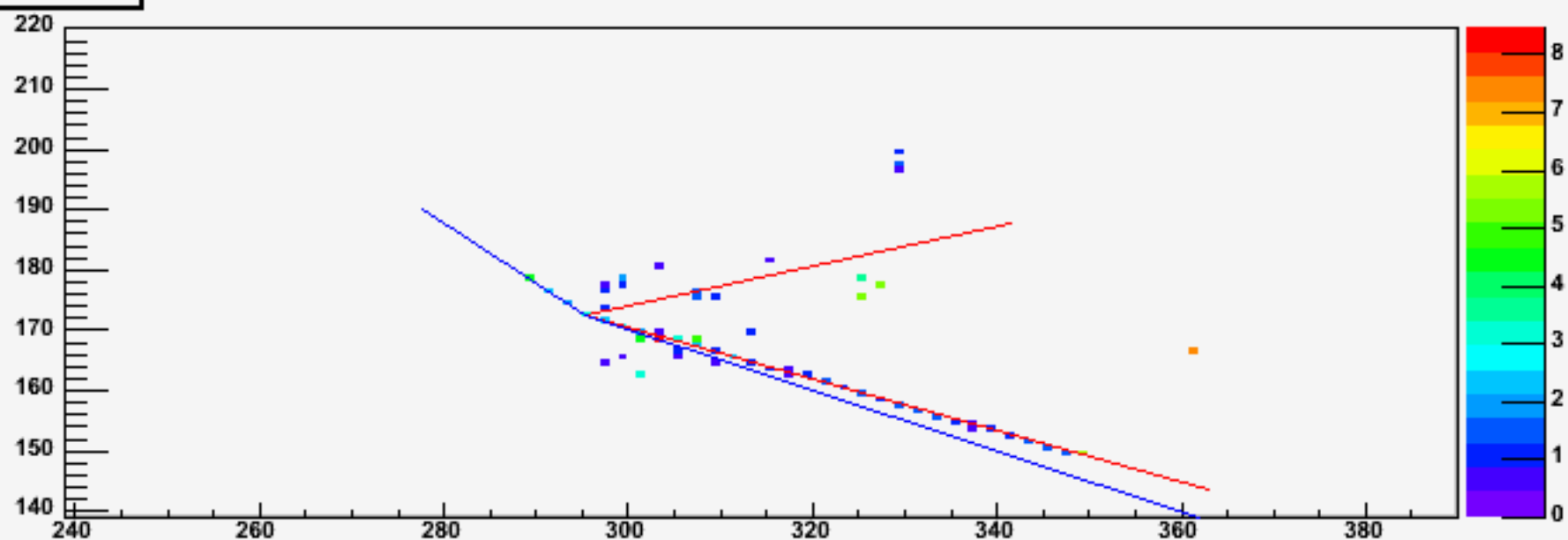


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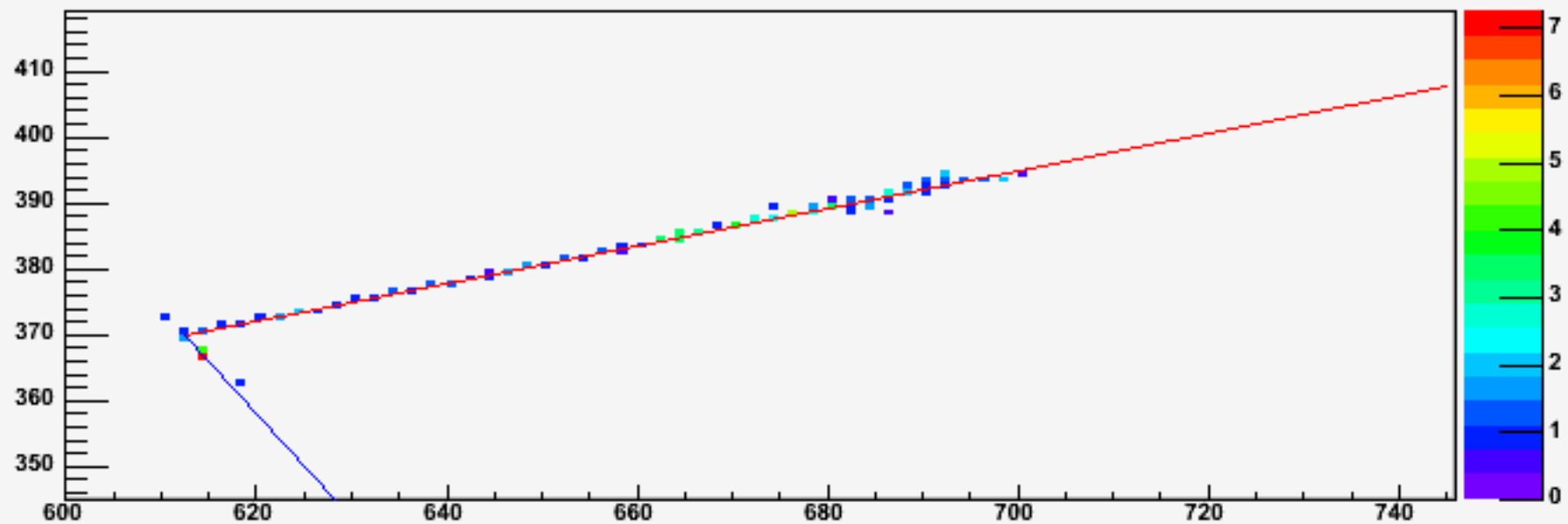




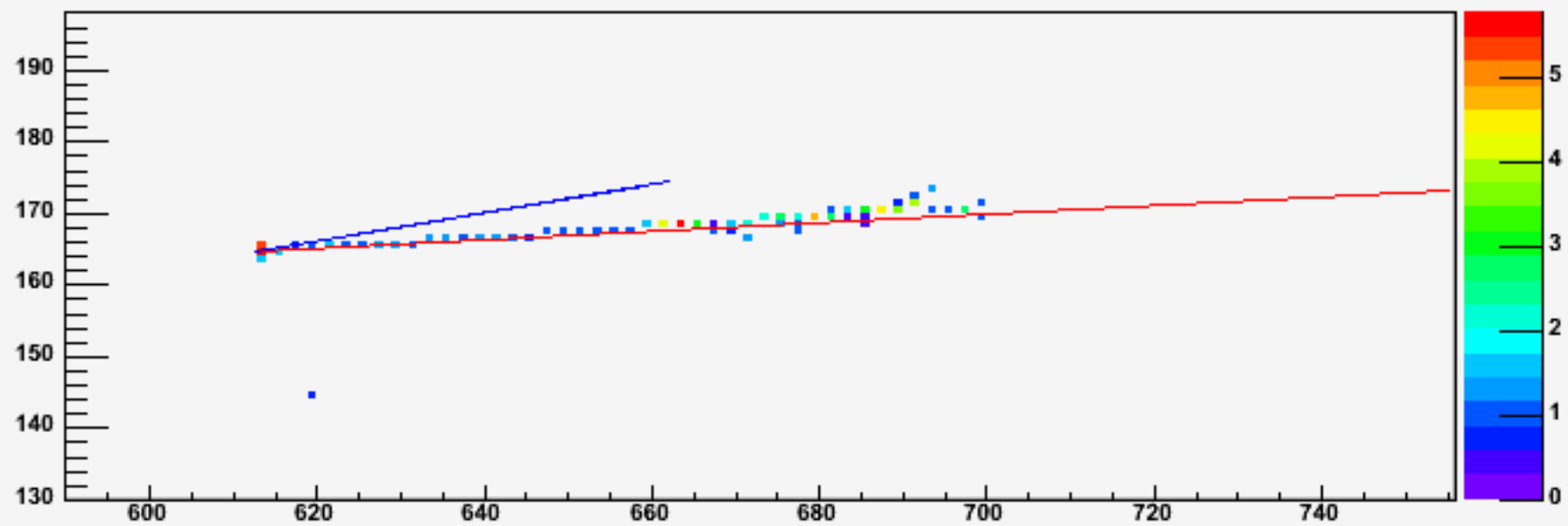
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XStripVsPlane



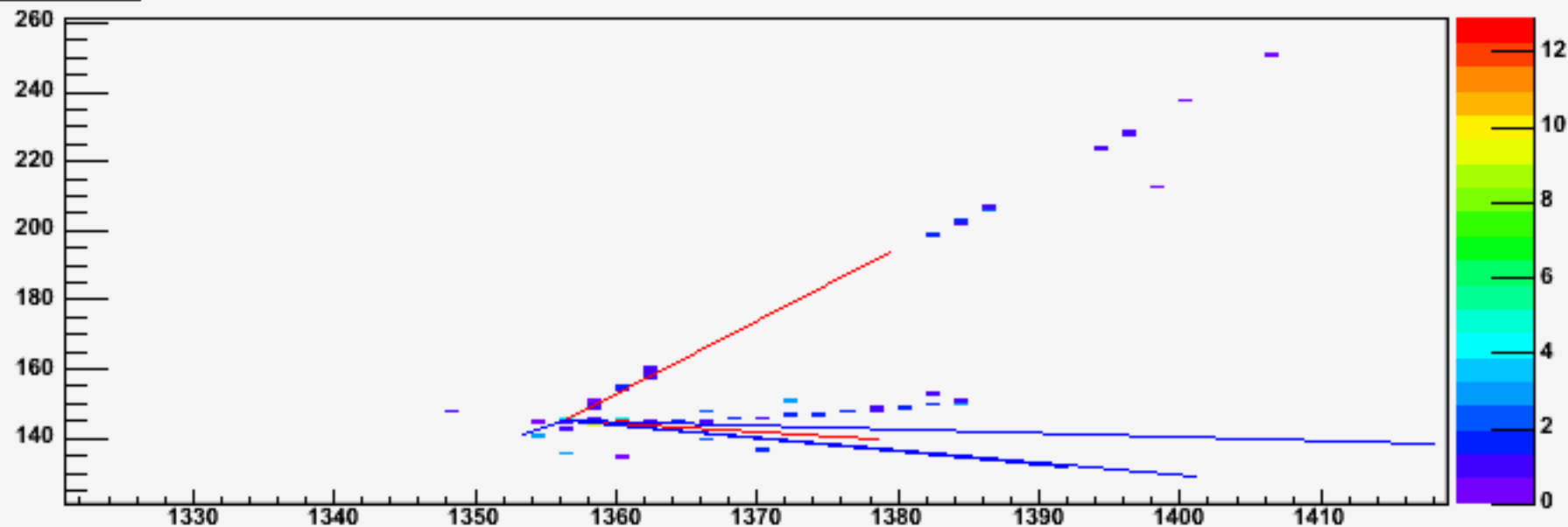
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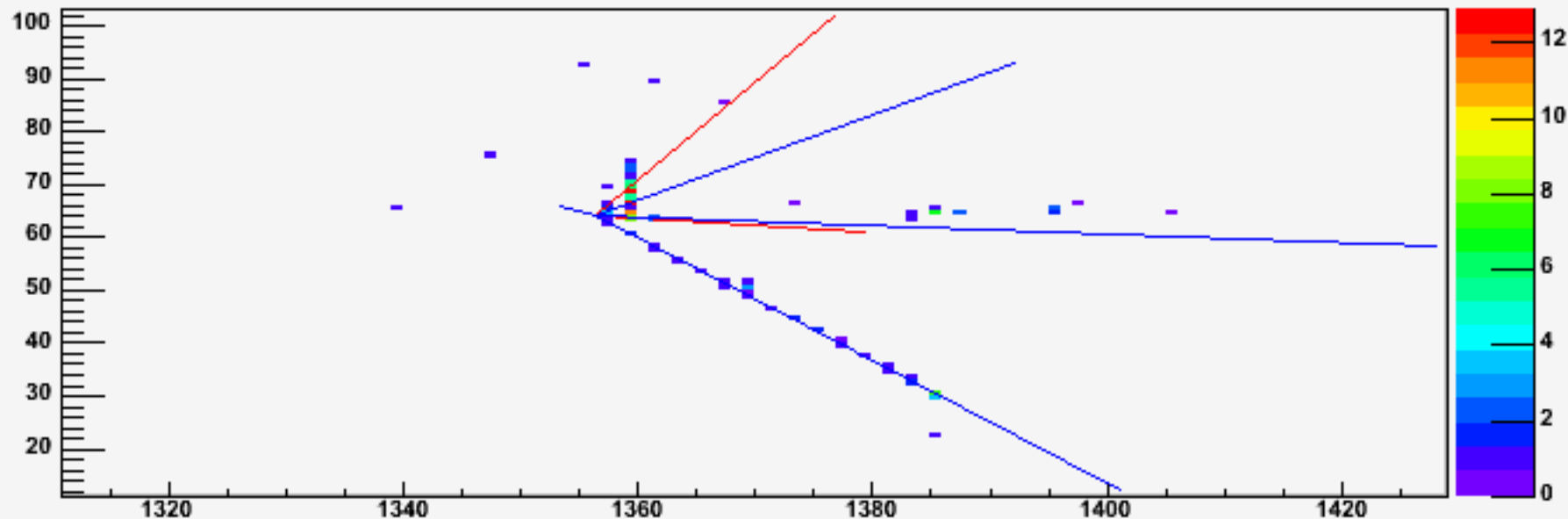


And now some failing ν_e CC
events

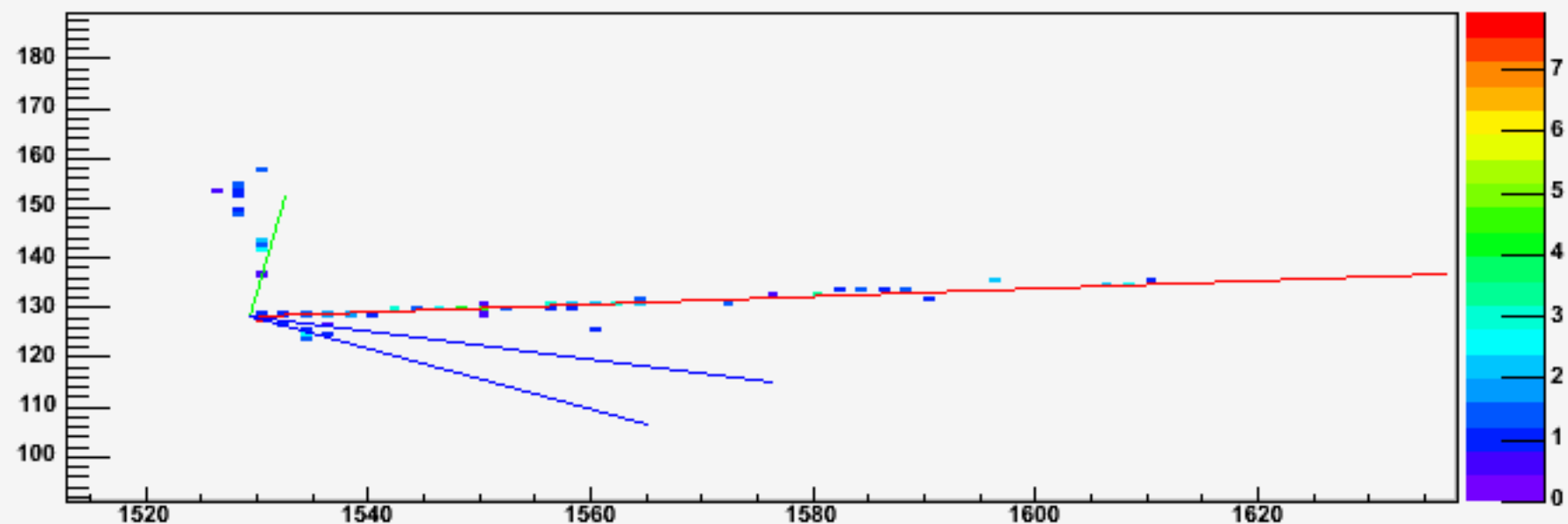
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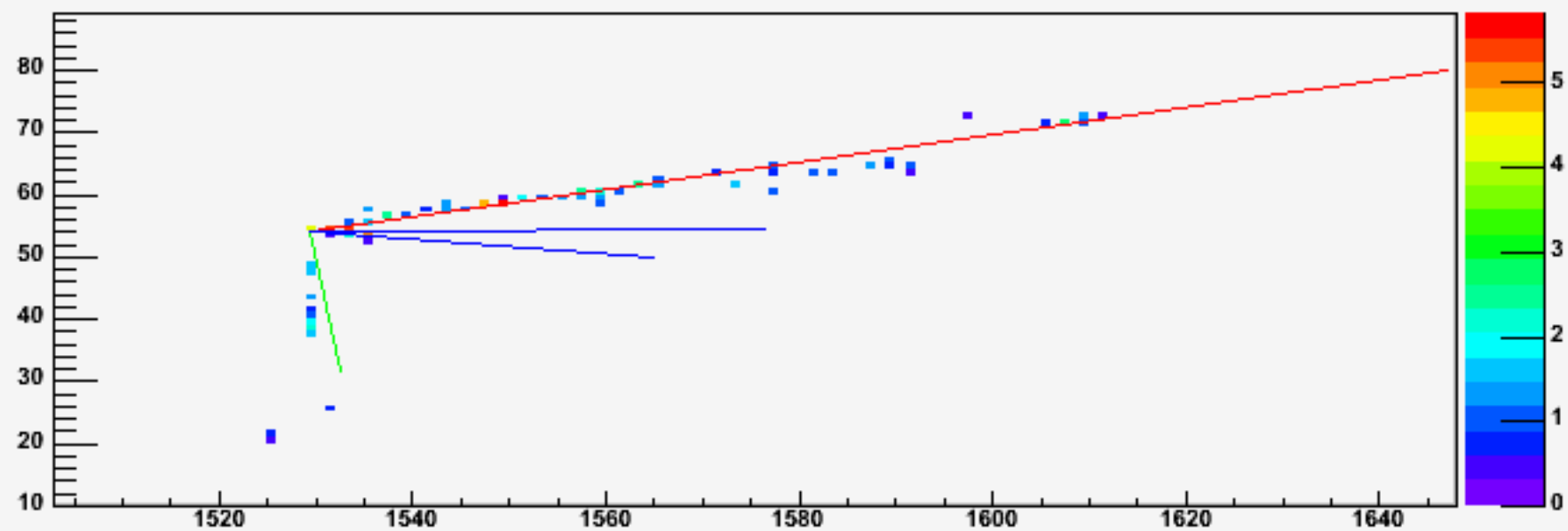
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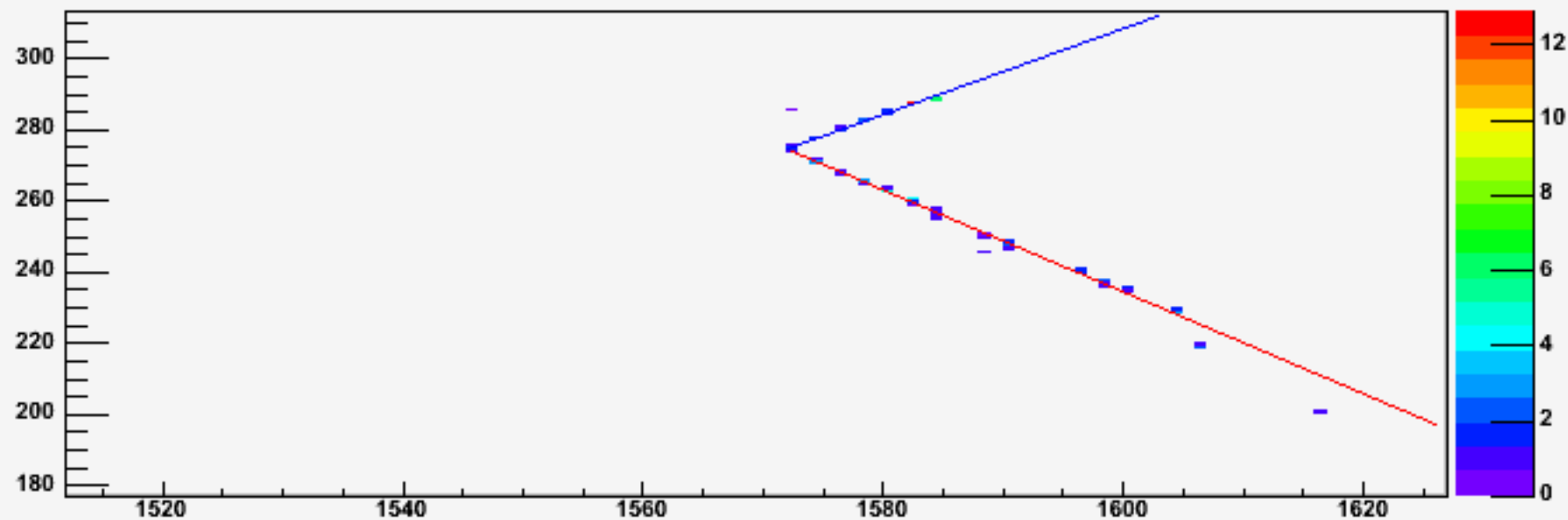
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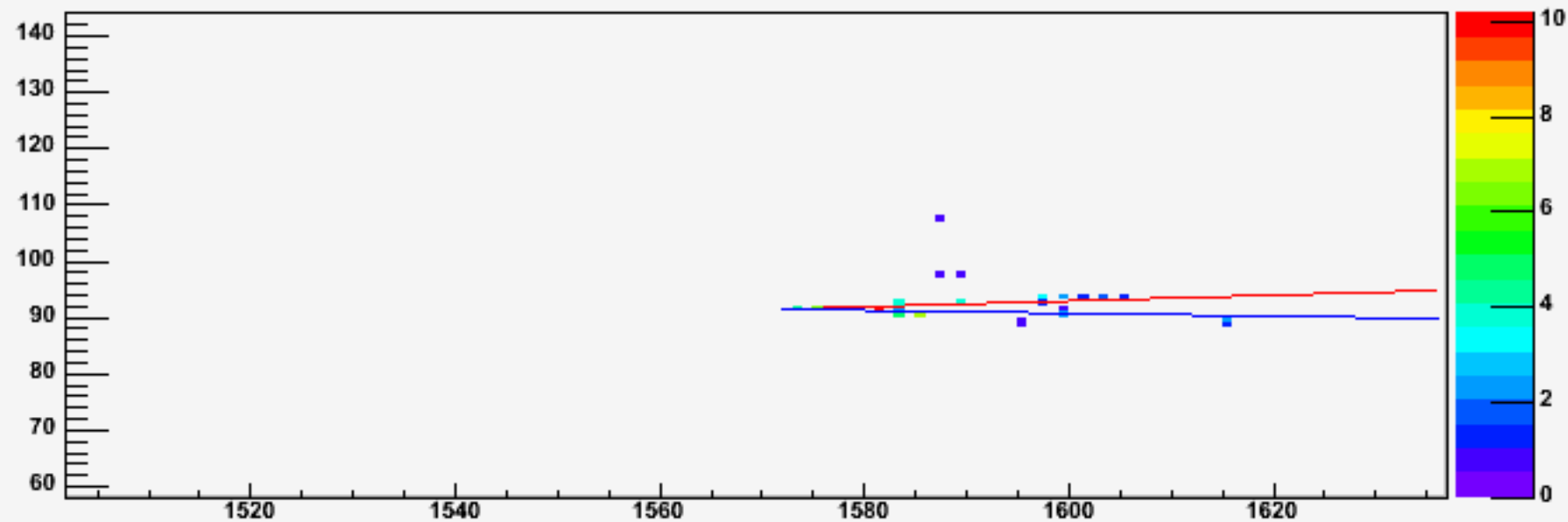
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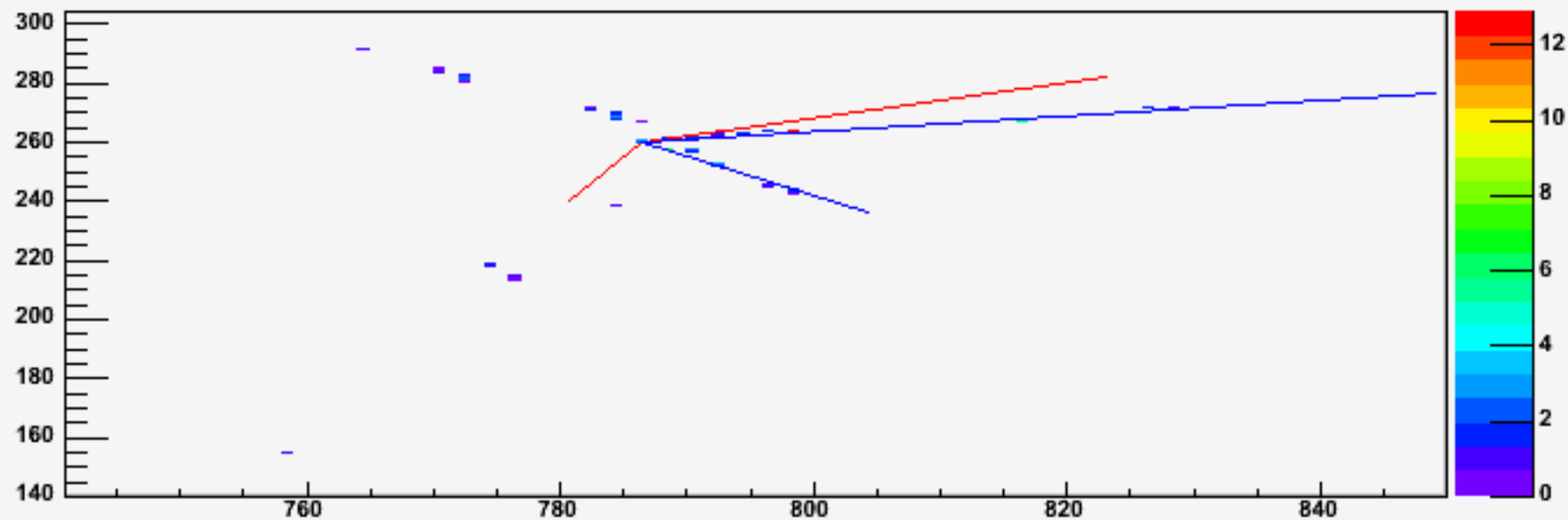
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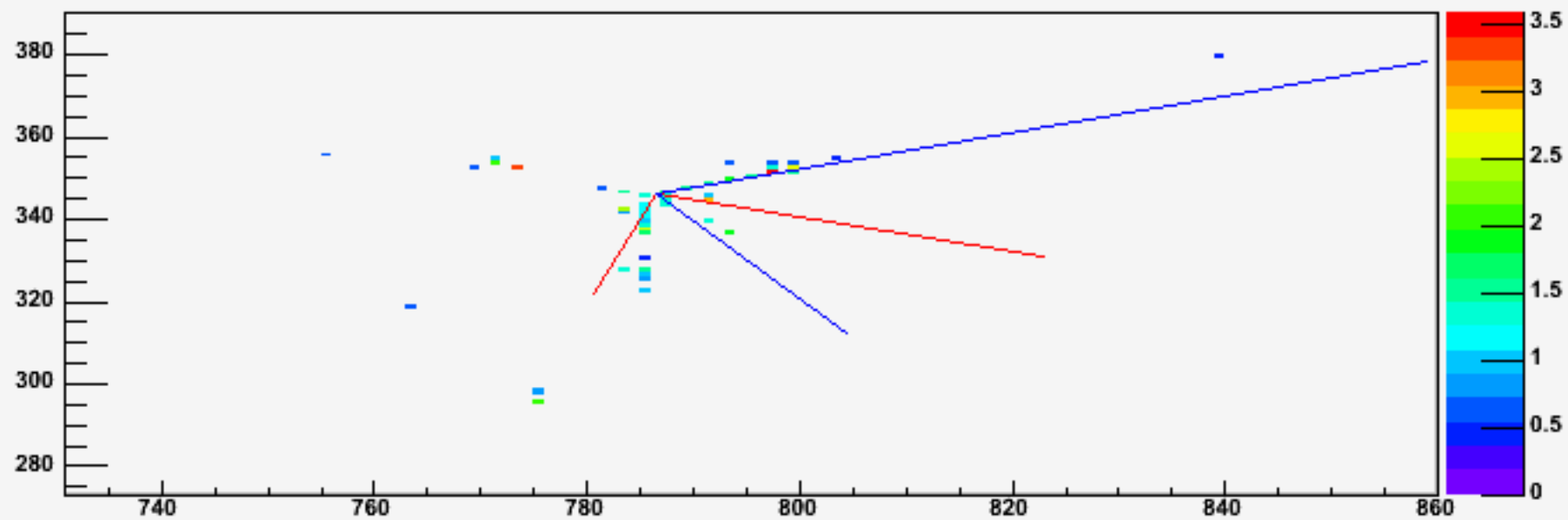
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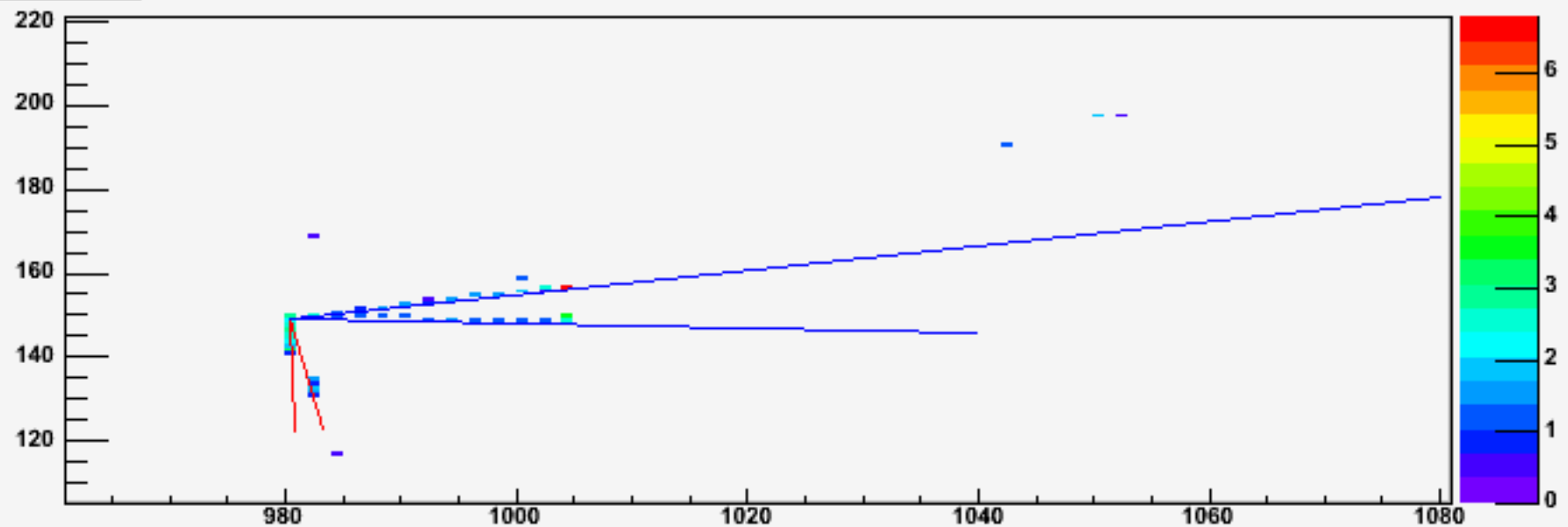
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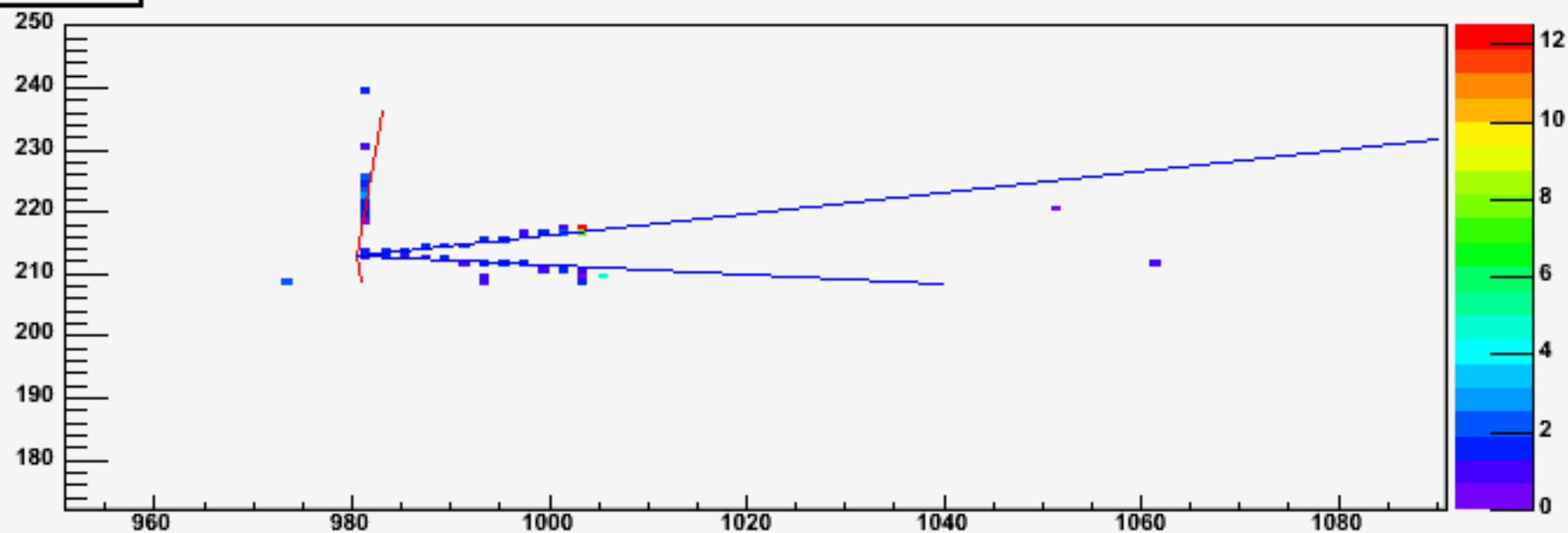
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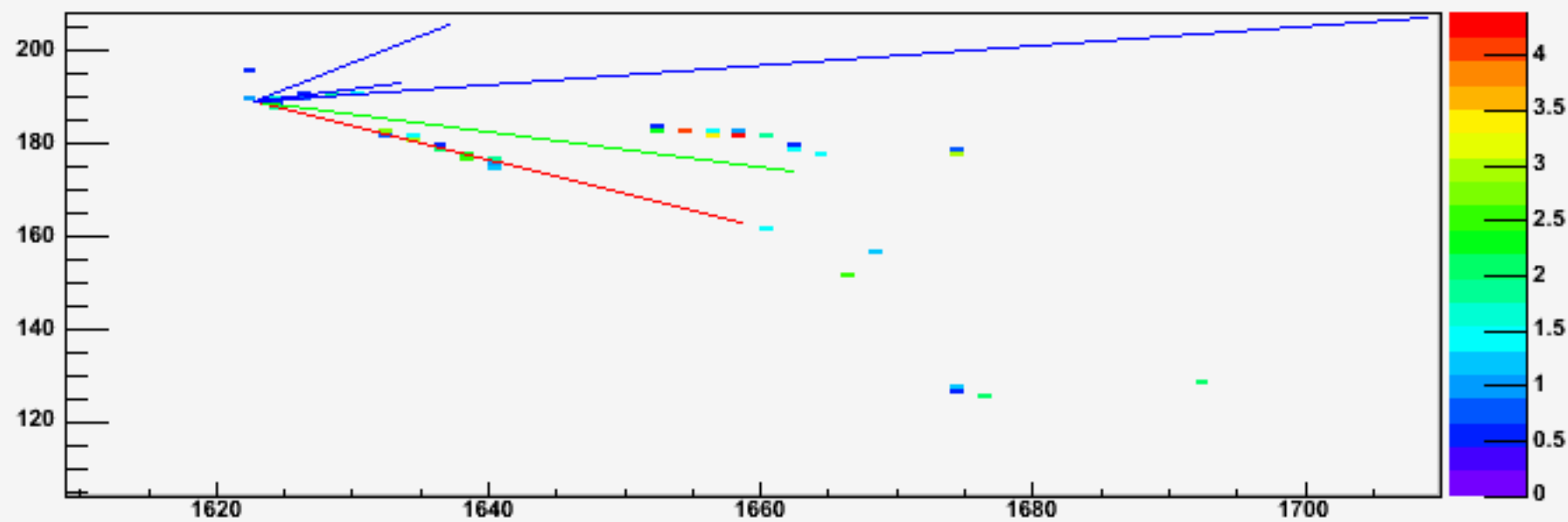
XStripVsPlane



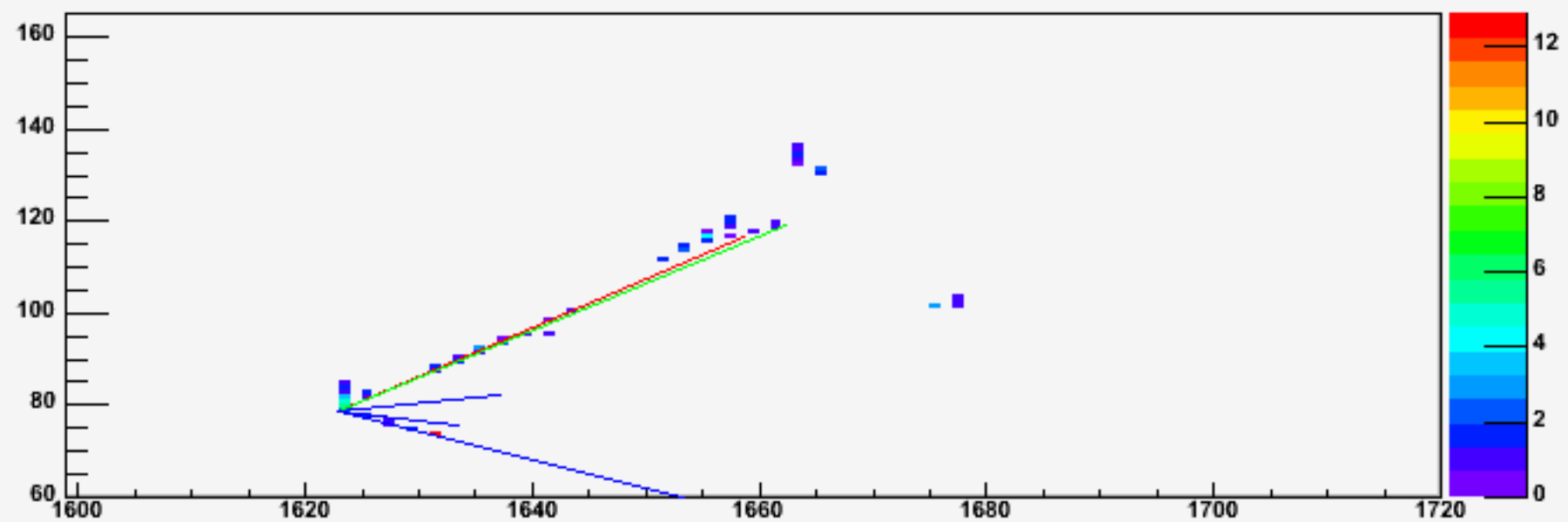
YStripVsPlane



XStripVsPlane

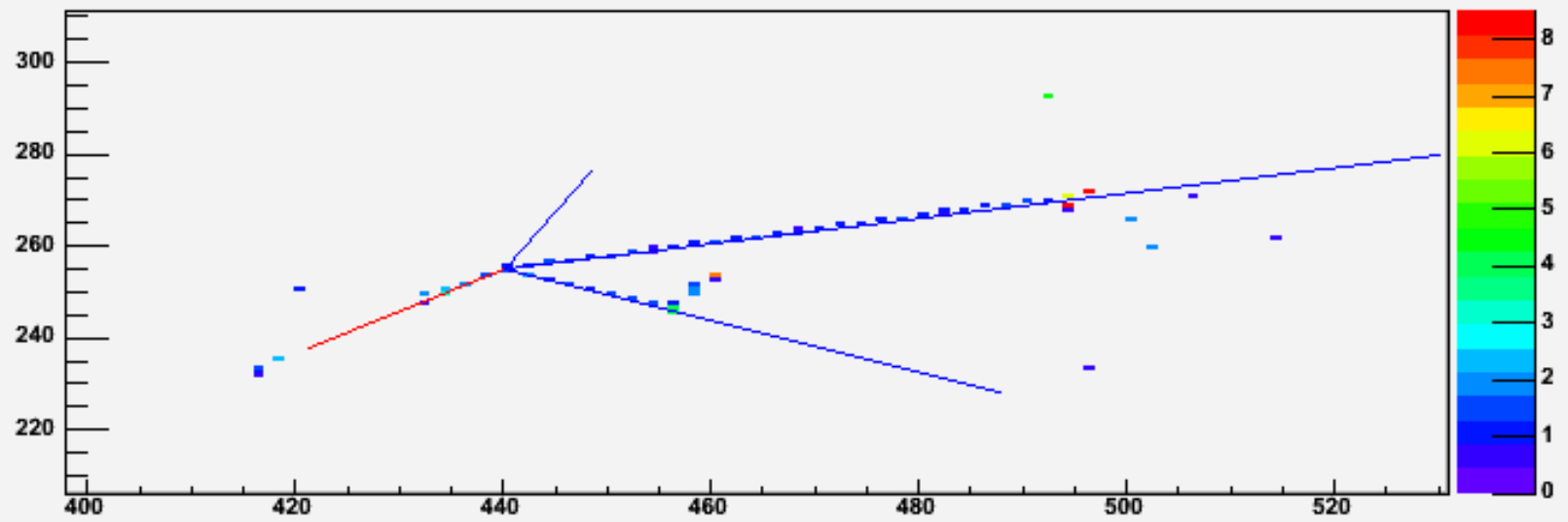


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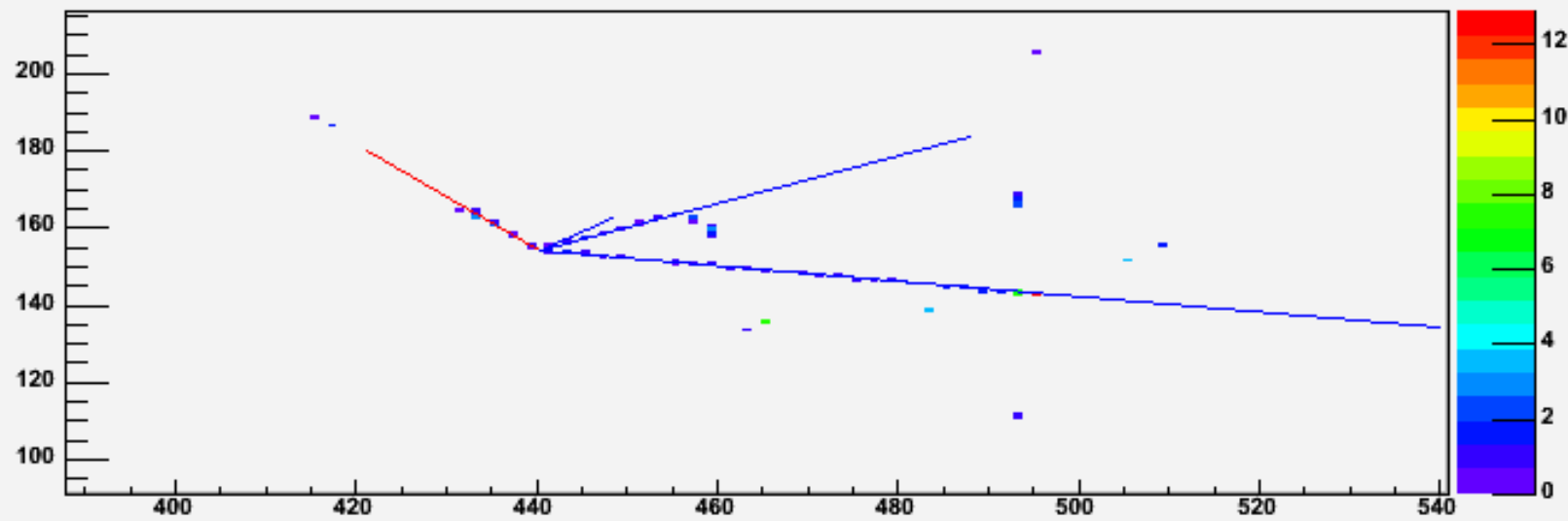


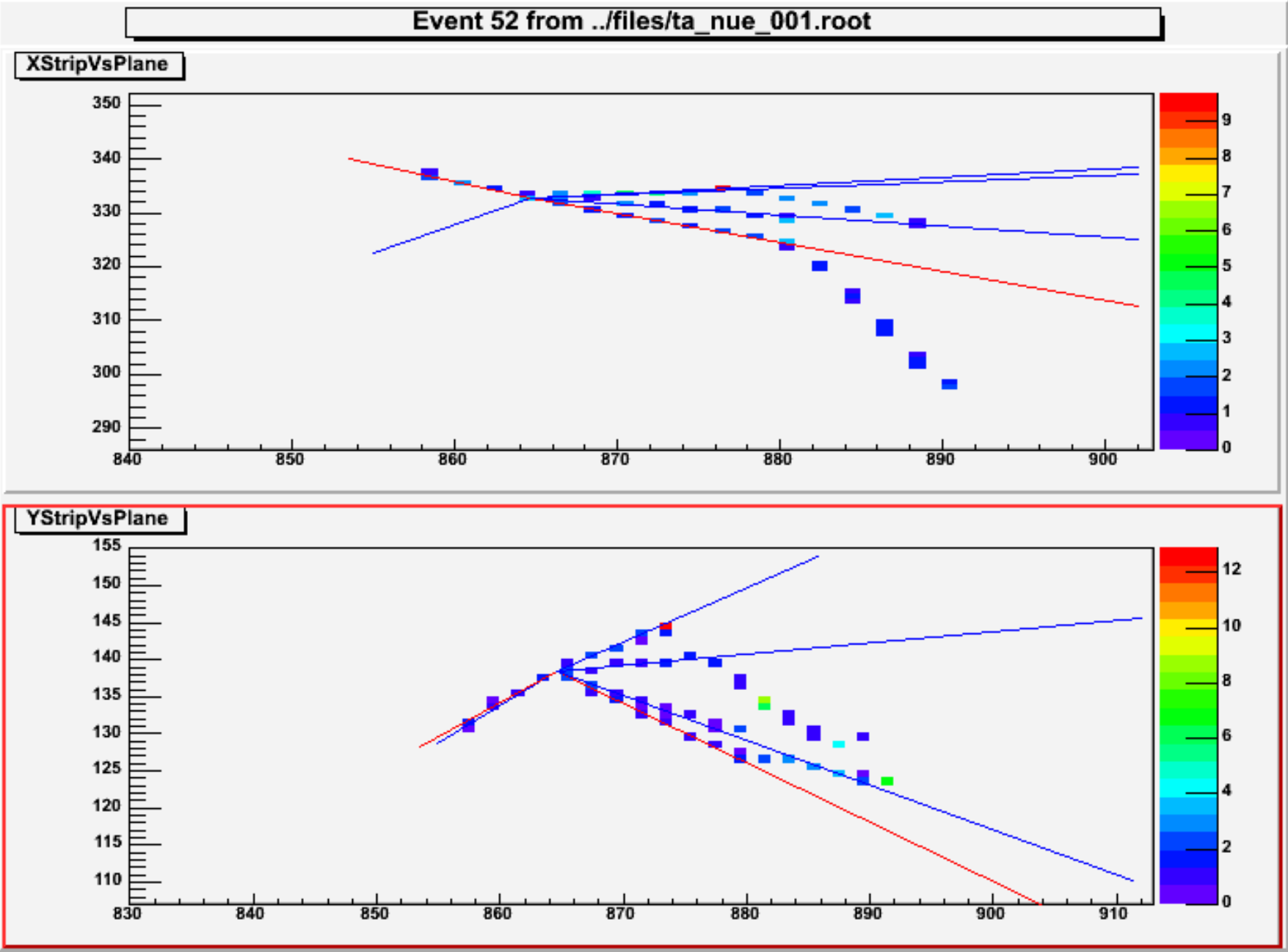
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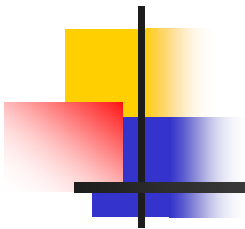
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YStripVsPlane



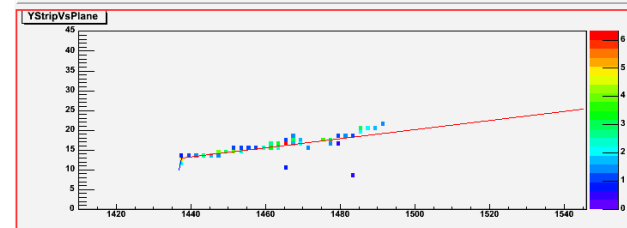
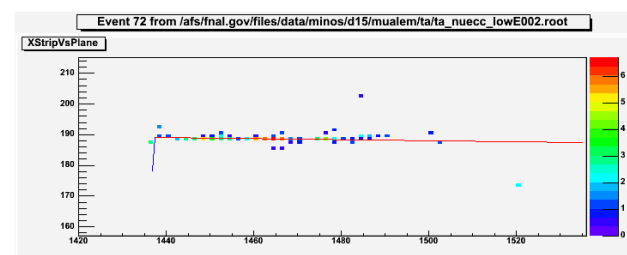
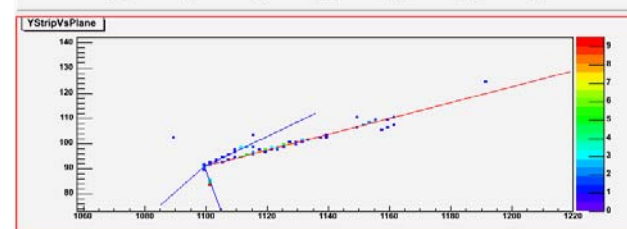
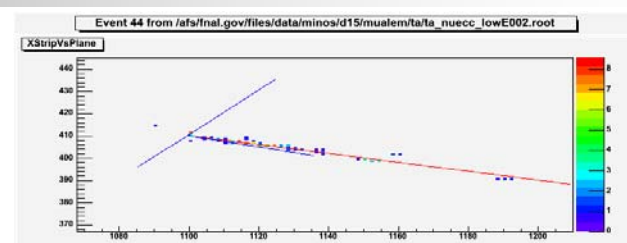
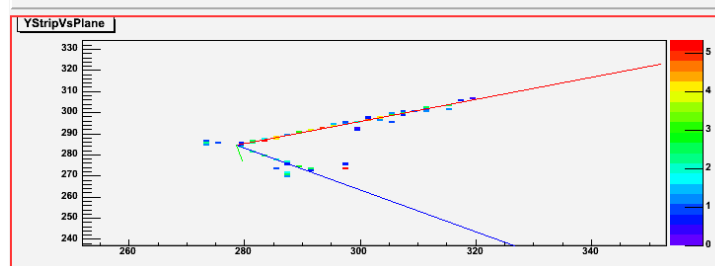
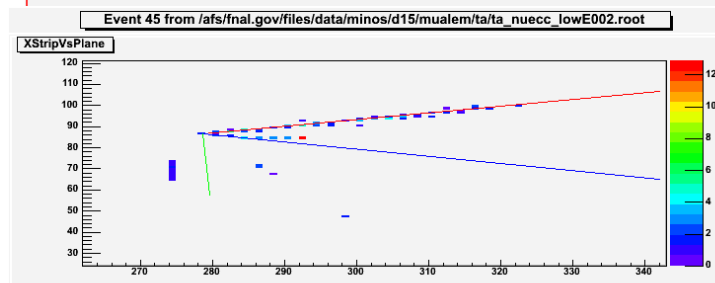
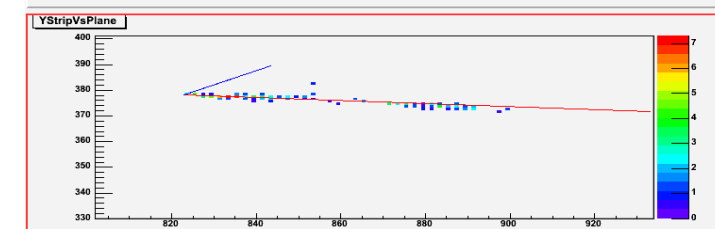
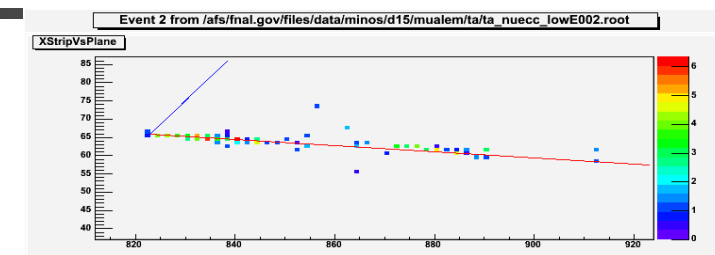




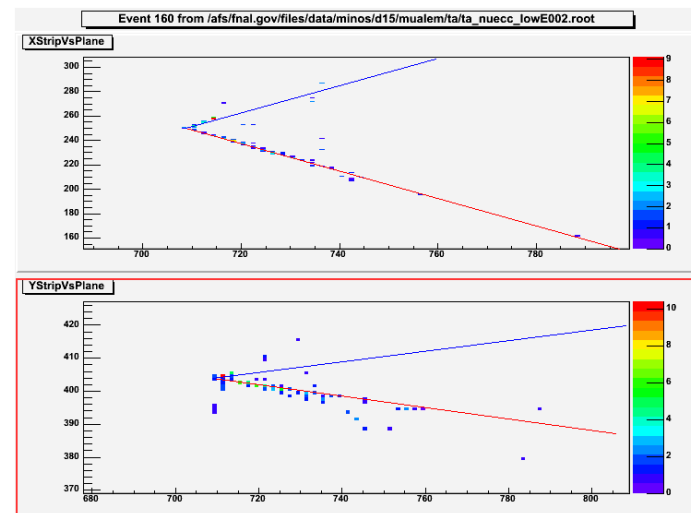
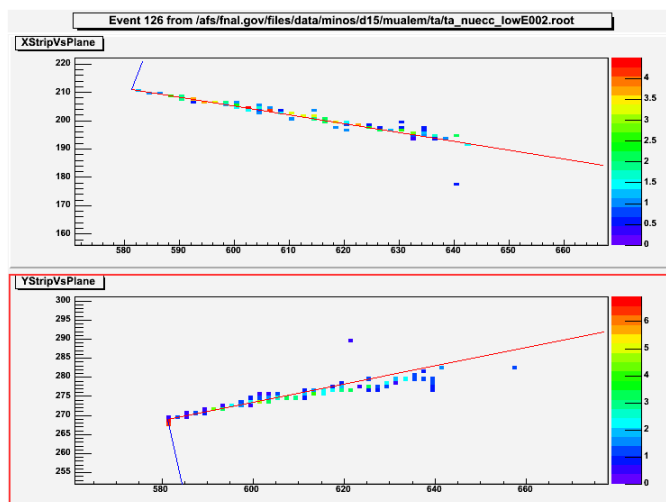
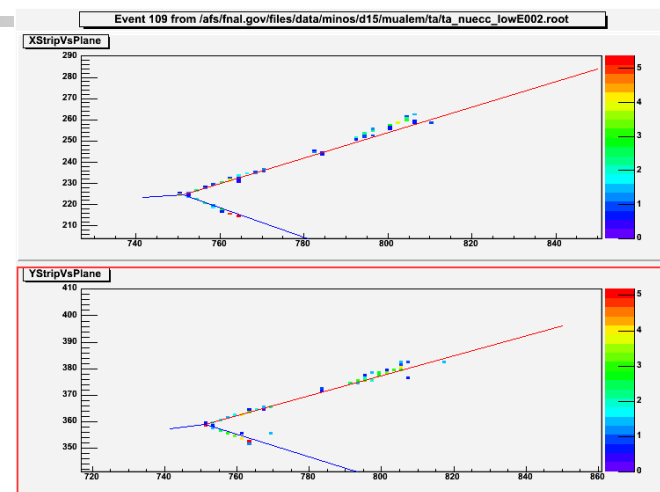
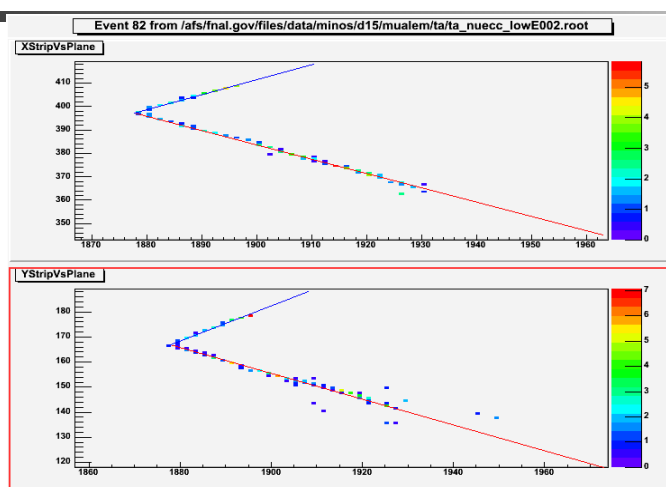
And now as antidote:

First 20 passing ν_e CC events

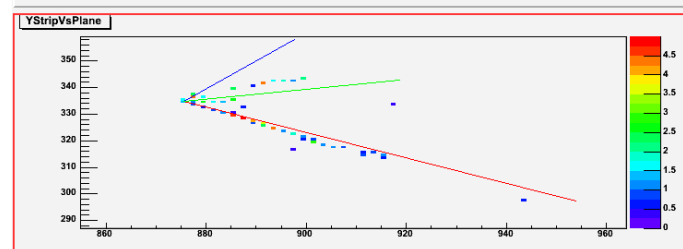
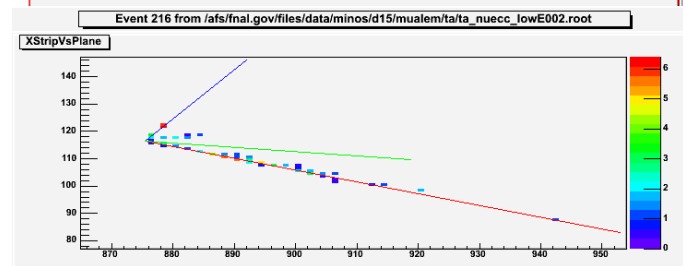
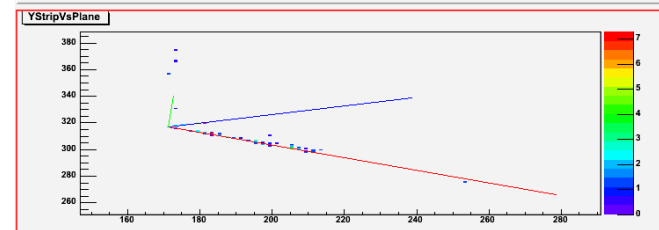
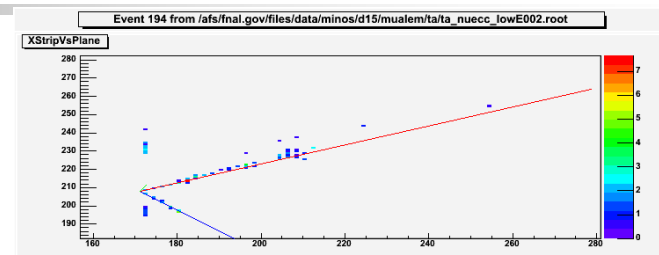
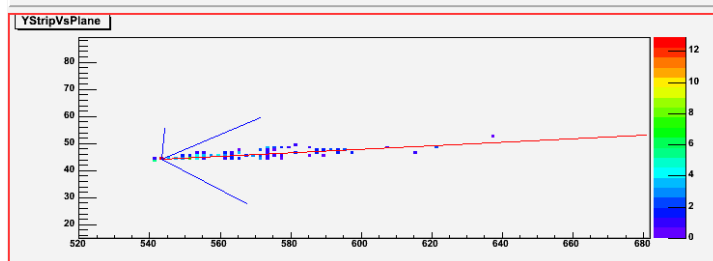
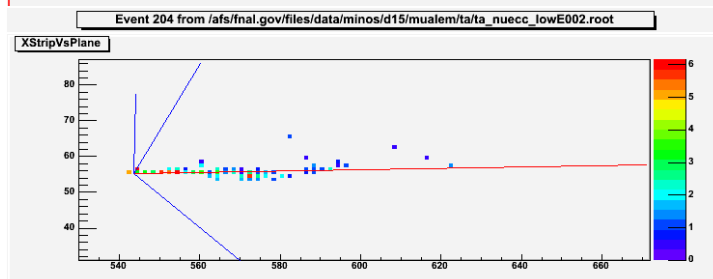
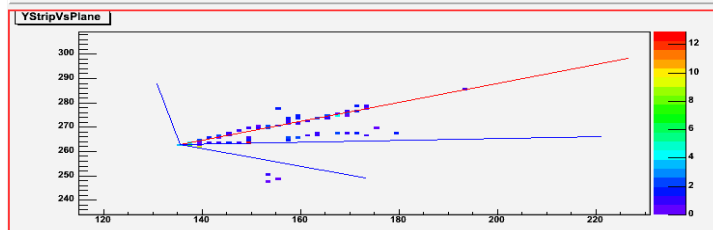
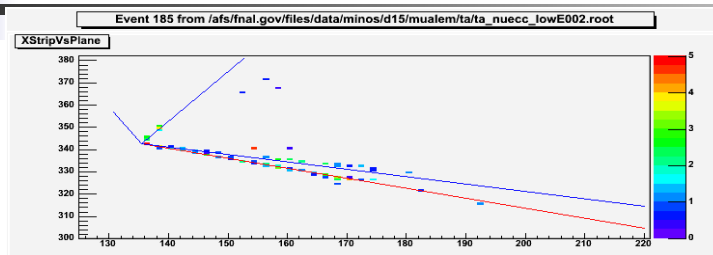
Good ν_e CC events (1)



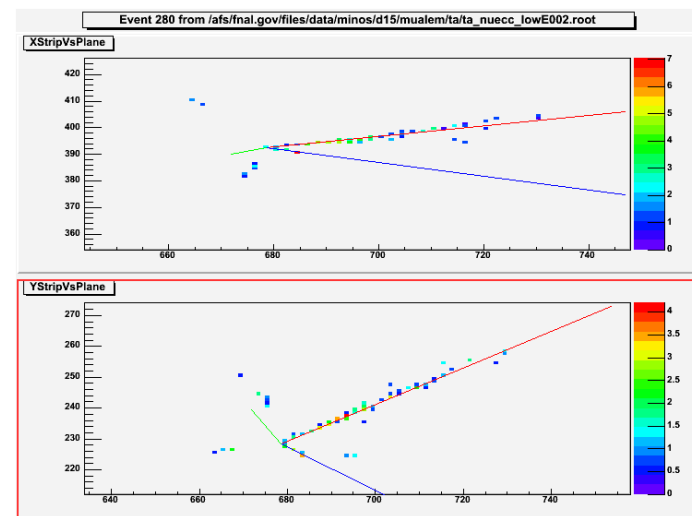
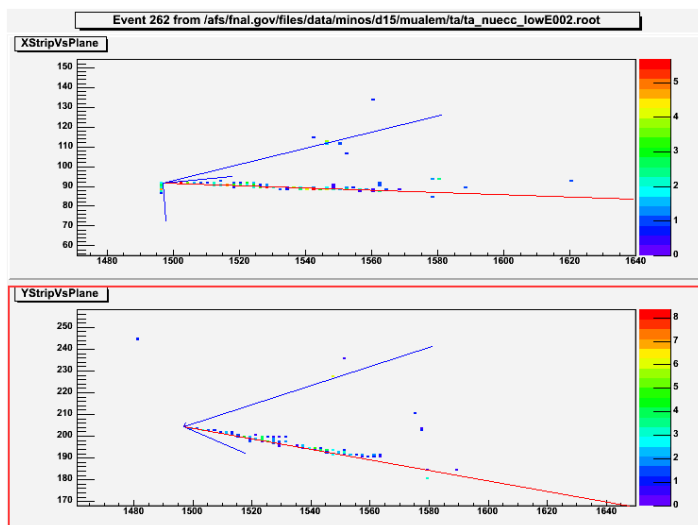
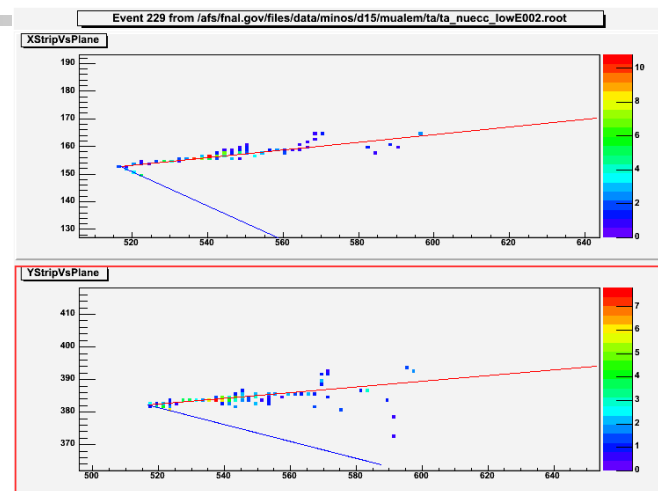
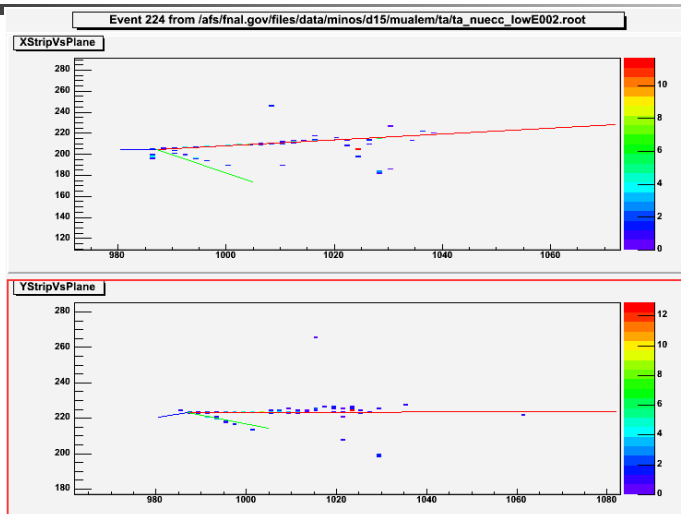
Good ν_e CC events (2)



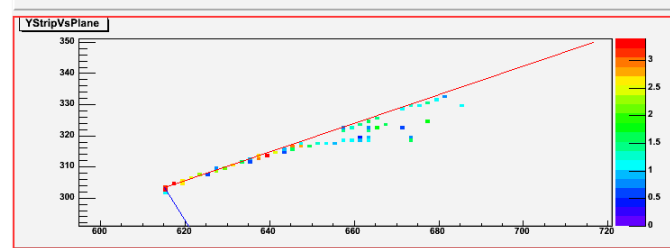
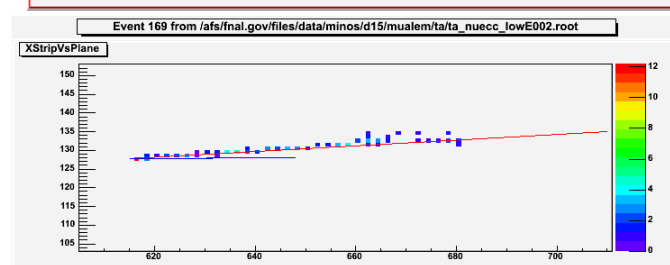
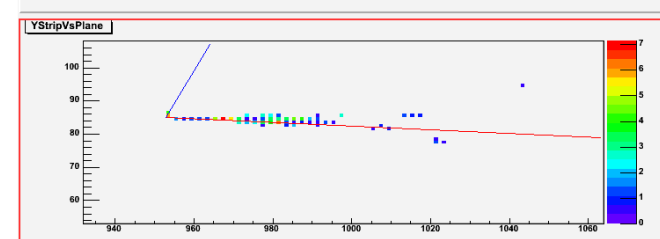
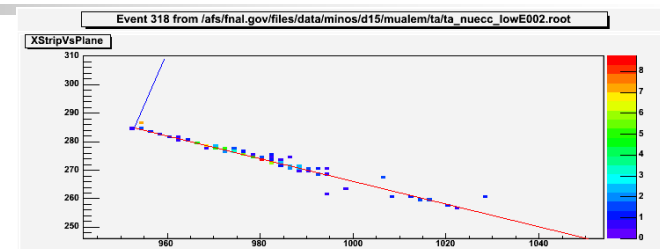
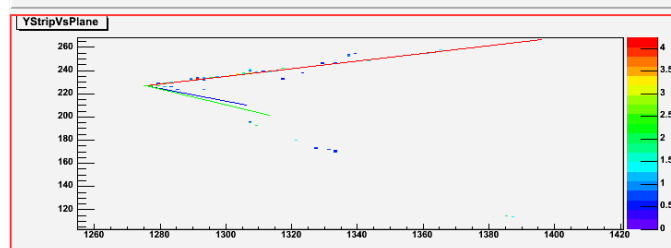
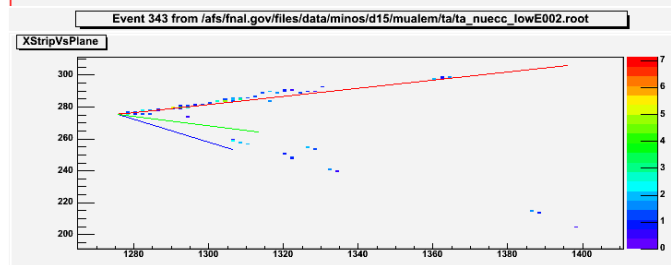
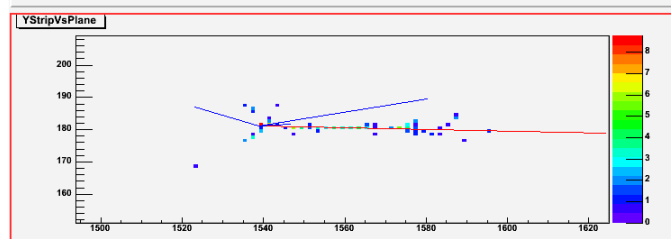
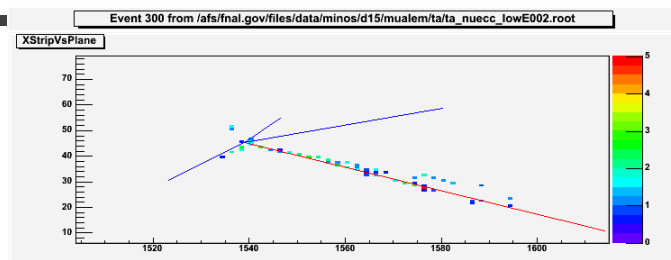
Good ν_e CC events (3)



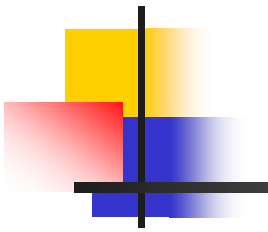
Good ν_e CC events (4)



Good ν_e CC events (5)

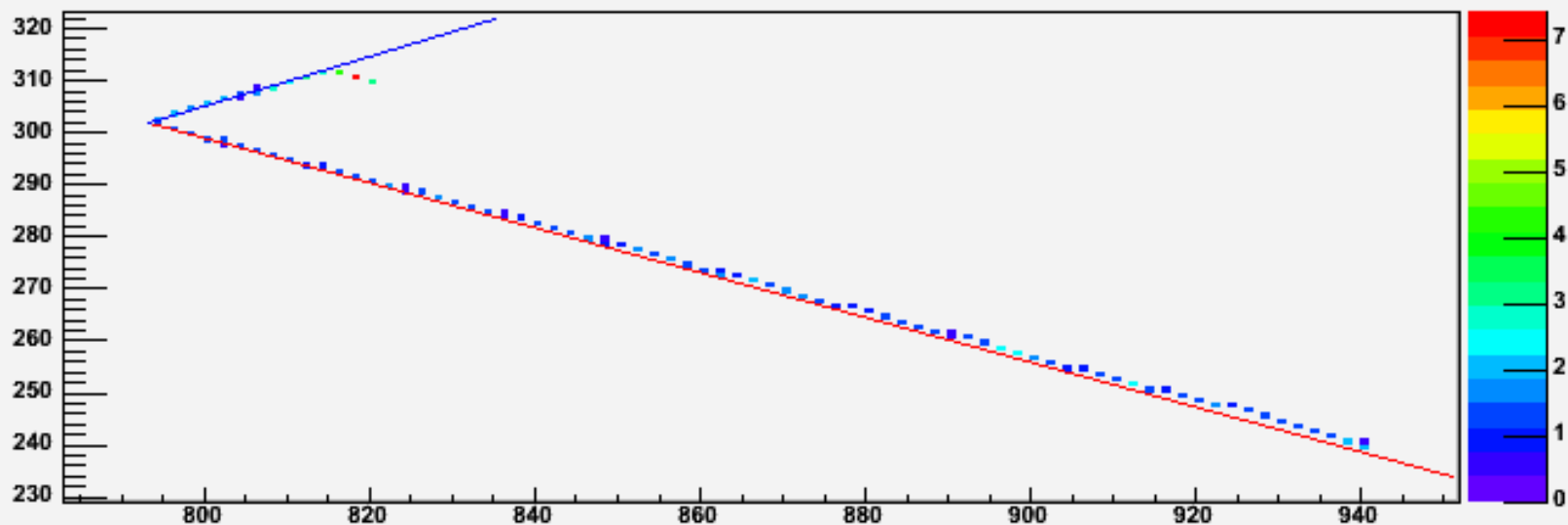


Other Possible Physics Measurements

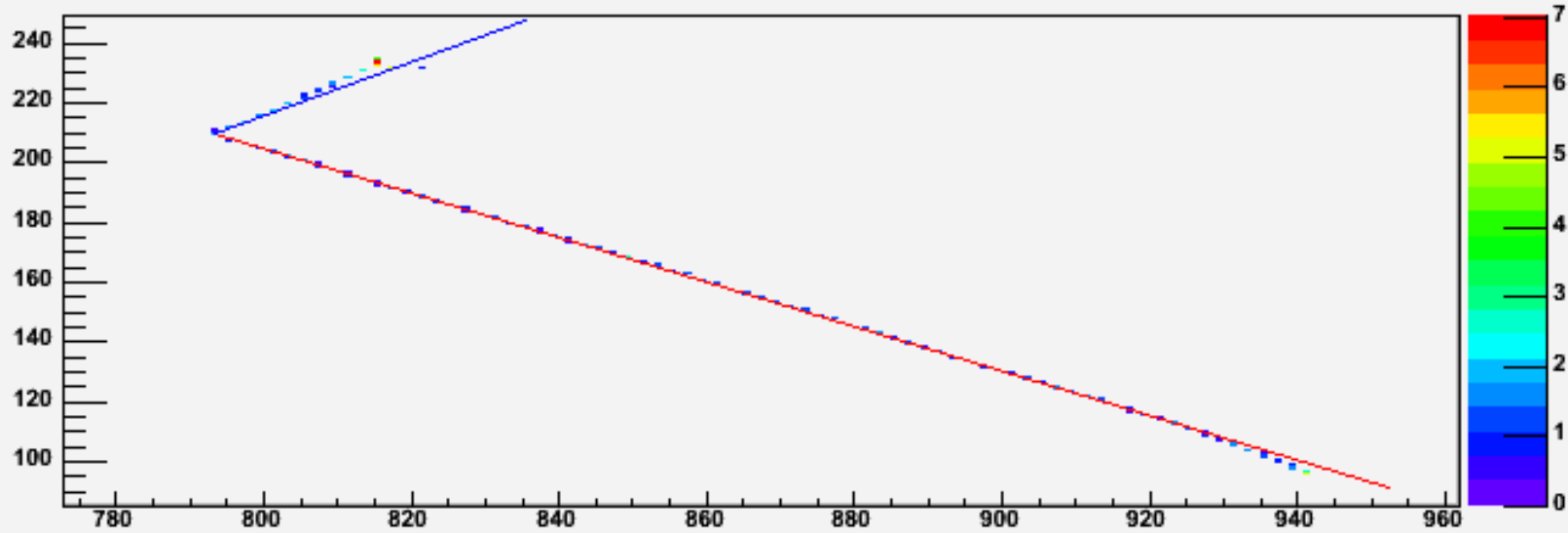
- 
- Could measure θ_{23} much better - quasielastics are well measured and constrained
 - Δm^2_{23} could be also measured better, less uncertainty on energy scale
 - Could set better limits on sterile ν contribution - should have subset of very clean NC events
 - Quasielastic ν_μ 's are very clean - two examples follow

Event 173 from /afs/fnl.gov/files/data/minos/d15/mualem/ta/ta_numucc_lowE002.root

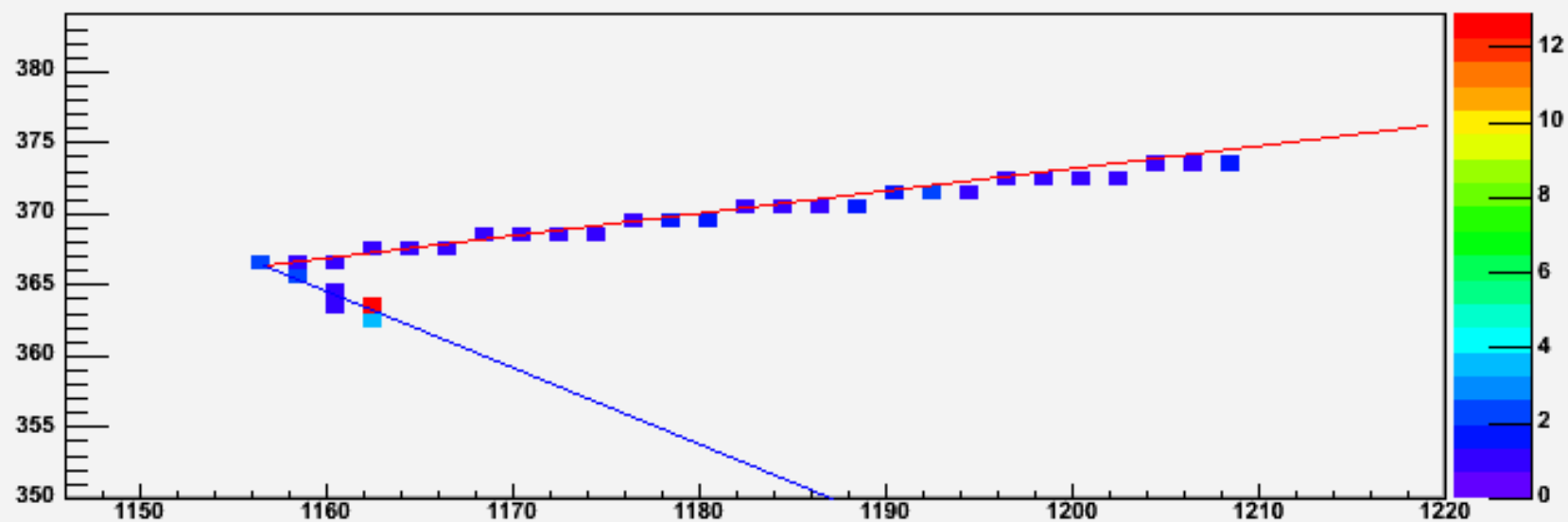
XStripVsPlane



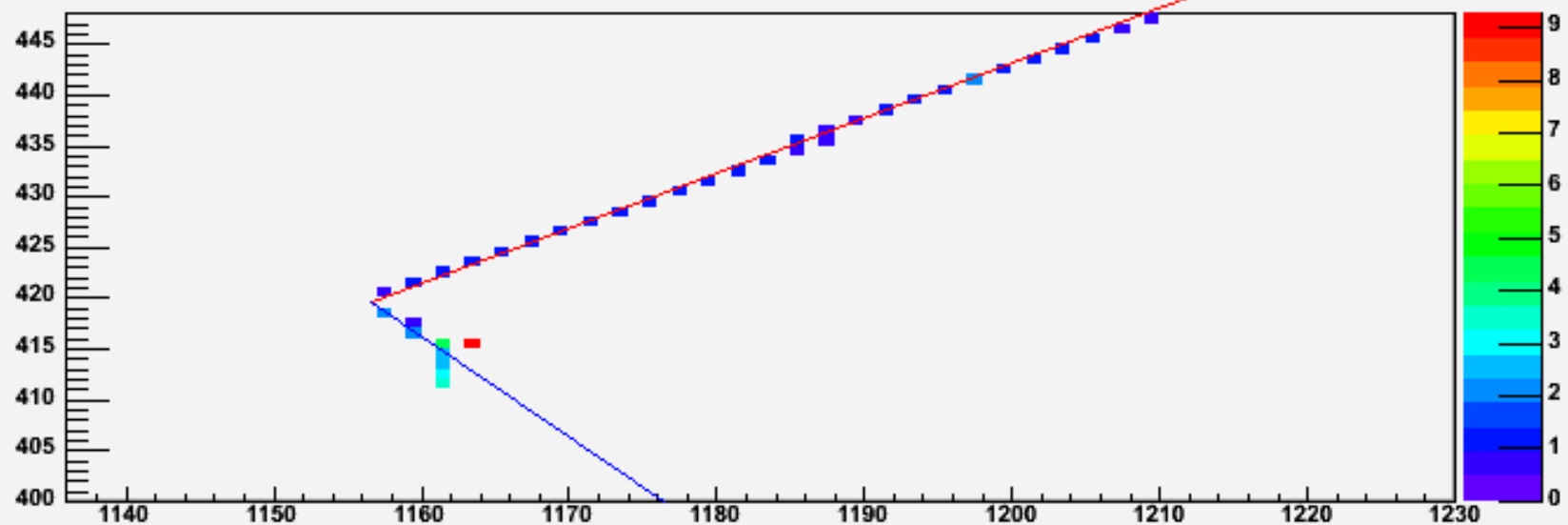
YStripVsPlane



XStripVsPlane

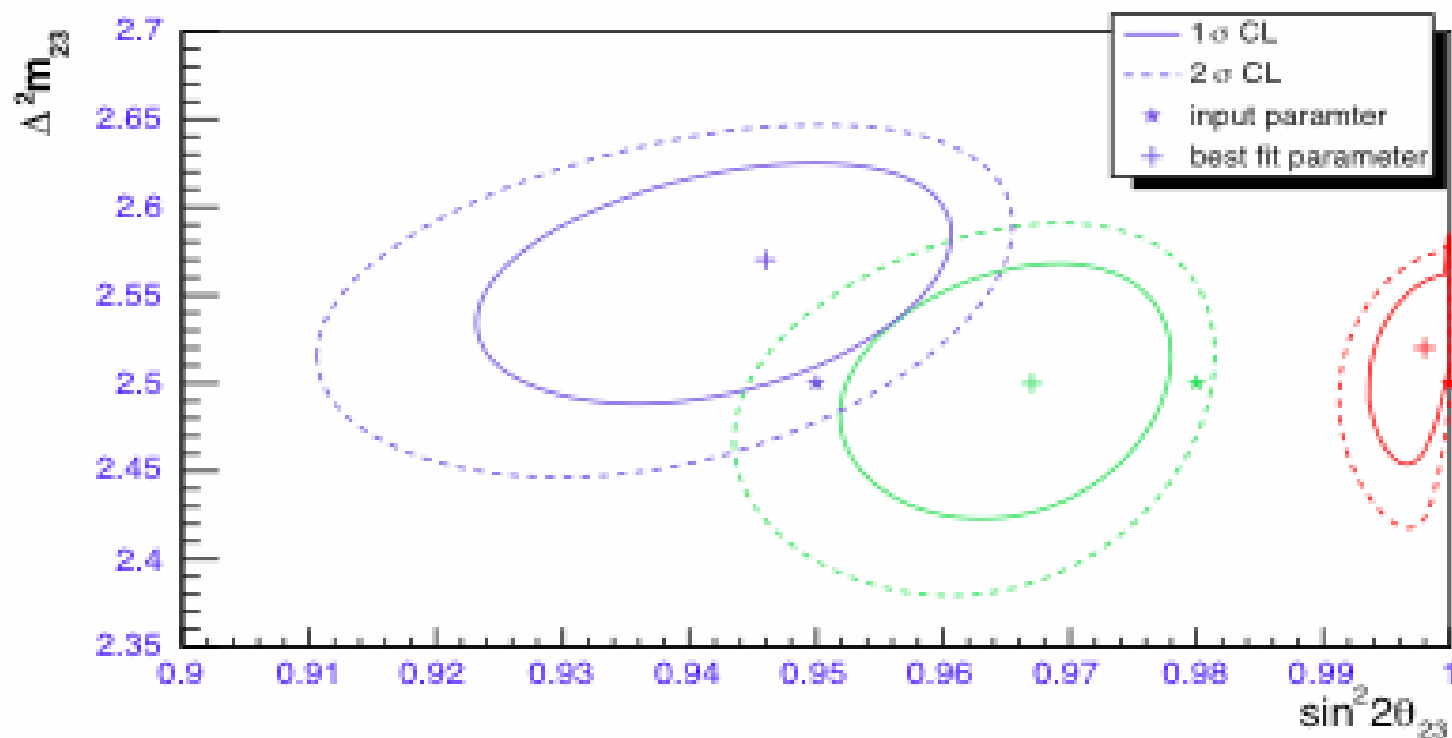


YStripVsPlane



Measurement of θ_{23} and Δm^2_{23}

sensitivities

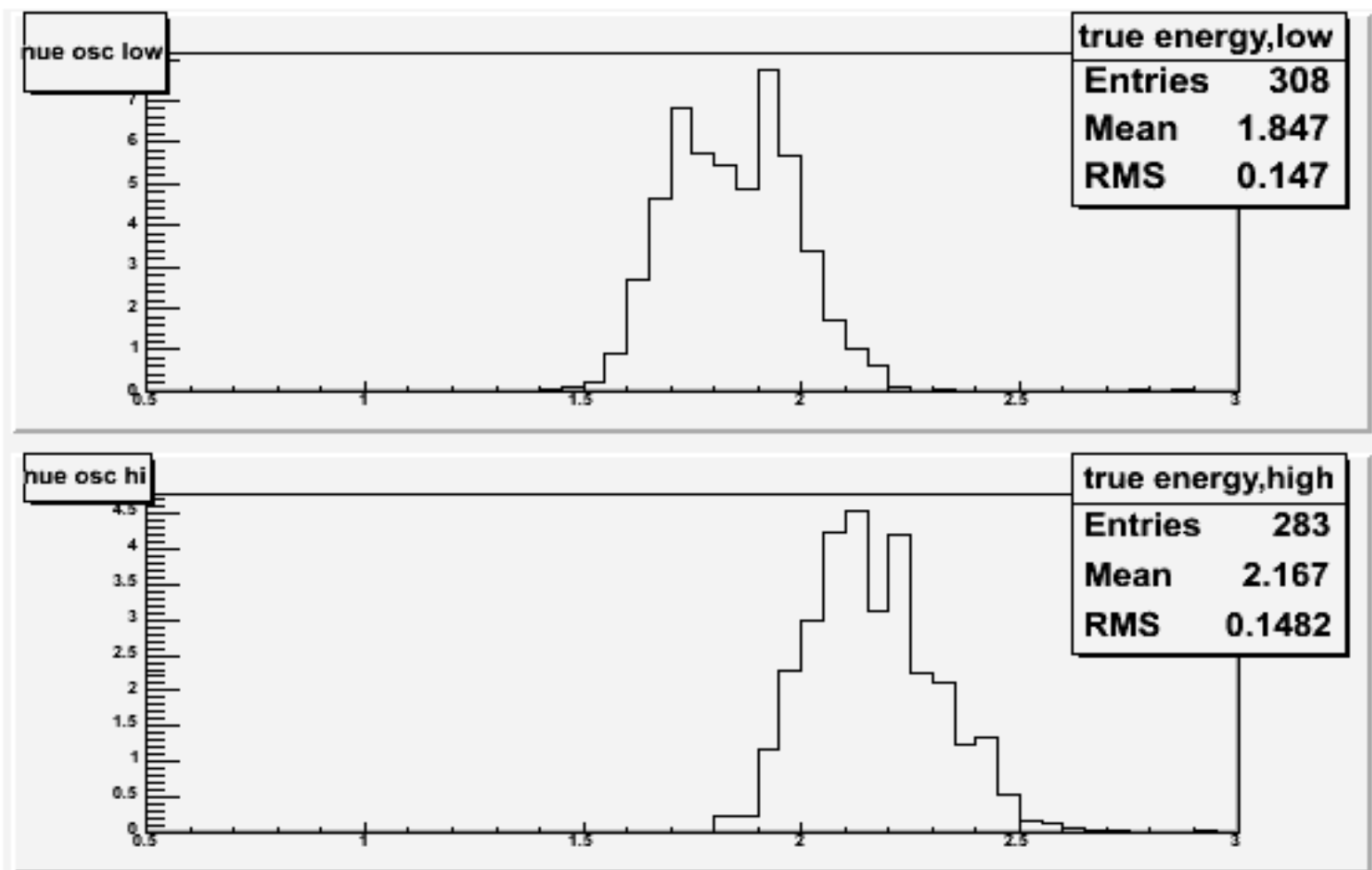




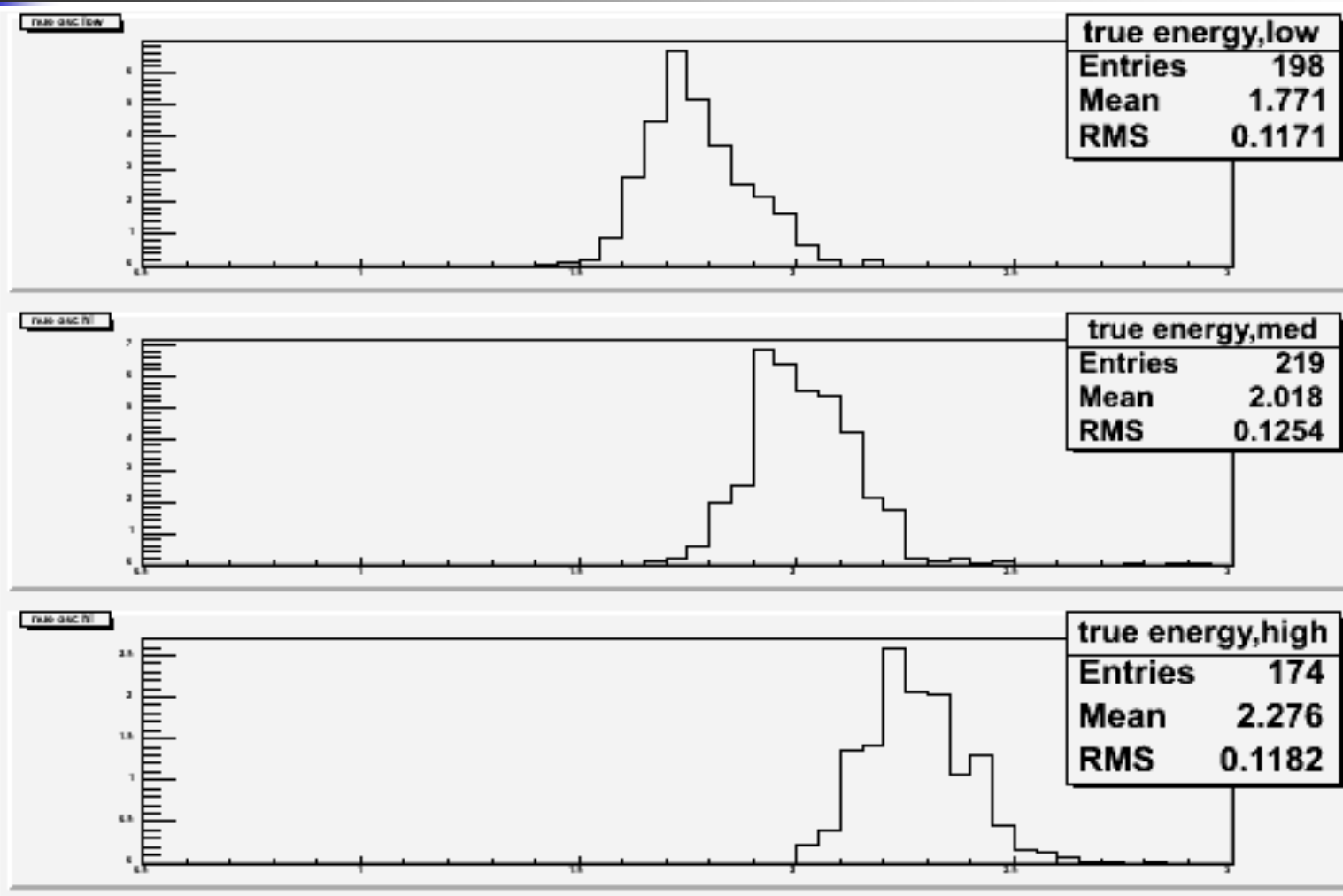
Other advantages

- Cosmic ray background drastically reduced; hence need for overburden is less likely
- Because of good energy resolution data can be divided by energy
- Not restricted by particle board sizes; more freedom in choice of detector dimensions
- Fiber, electronics cost inversely proportional to area of cell -> more freedom in choice of cell dimensions. Maybe other dimensions are better than 3.9×2.8 (more light/cell, better transverse segmentation)
- Near Detector becomes simpler and more like far detector; less need to measure NC and CC

Dividing data into 2 energy bins



Dividing data into 3 energy bins





Conclusions

- The initial round of simulations shows that this approach could have significant advantages over the current baseline design
- There is still a lot of room for improvement in analysis, probably also in choice of hardware parameters
- Additional steps that should be taken next are:
 - Understanding of construction and installation issues
 - Optimizing the design, eg packaging of electronics
 - Obtaining reliable cost estimate